Washington

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Source Area Delineation Report

Big Lost River Valley Hydrologic Province

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Prepared for

Idaho Department of Environmental Quality

Prepared by

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1.0 INTRODUCTION

1.1 Background

In 1996, Congress amended the Safe Drinking Water Act to emphasize the protection of surface and ground-water sources used for public drinking water. The amendments require that each state develop a Source Water Assessment Plan (SWAP) for public drinking water sources, conduct assessments of all public water systems (PWSs), and make the assessments available to the public. In Idaho, the SWAP was developed and is being implemented by the Idaho Department of Environmental Quality (IDEQ) with input from stakeholders. The Idaho SWAP was completed and approved by the U.S. Environmental Protection Agency in November of 1999.

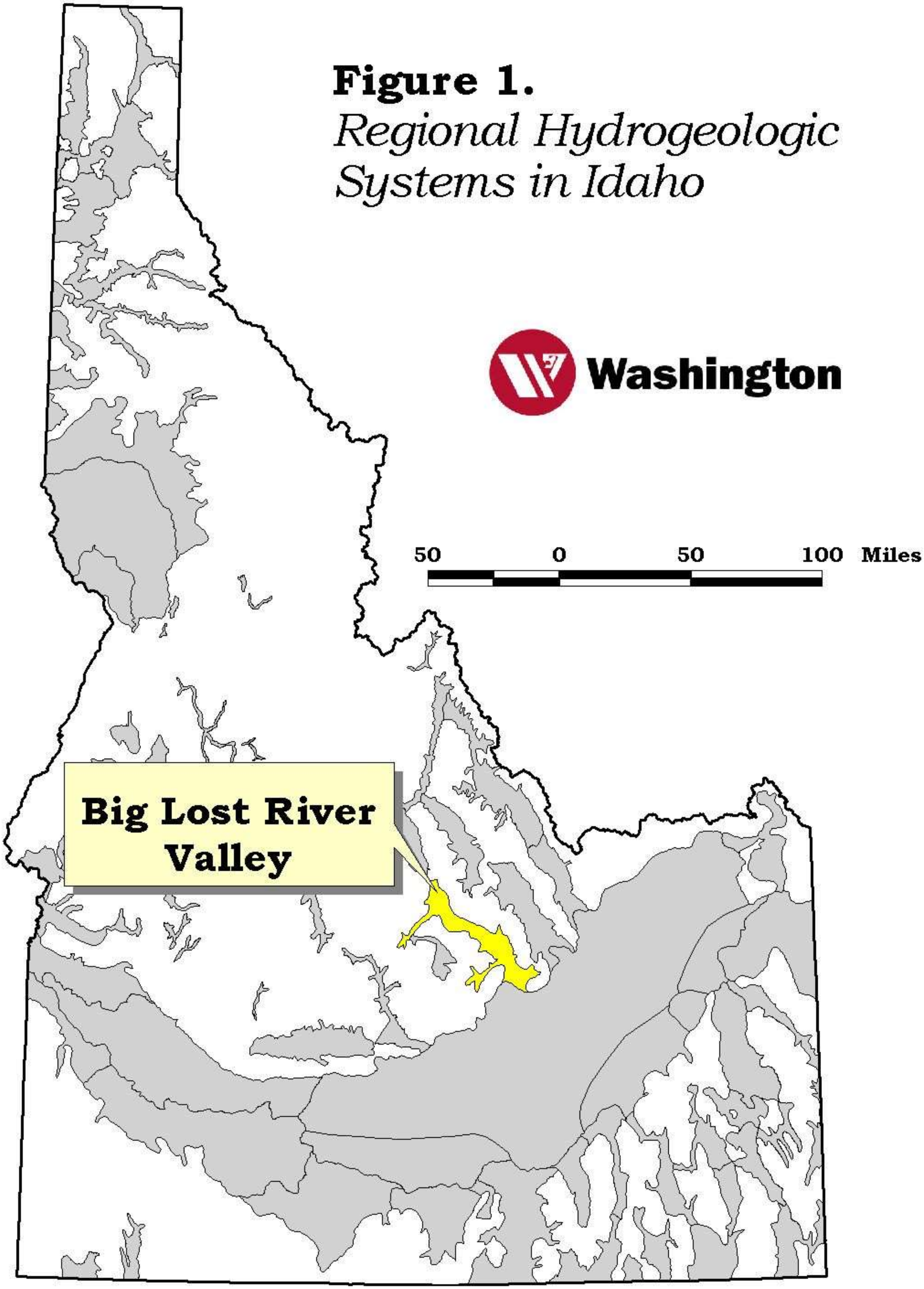
The primary goal of Idaho's source water assessment process is to develop information that enables PWS owners, operators, consumers, and others to initiate and/or promote actions to protect their drinking water sources. Each source water assessment involves three primary components:

1. Determining the area of contribution for each source (source area delineation),
2. Identifying potential sources of drinking water contamination within the area of contribution (contaminant source inventory), and
3. Determining the vulnerability of the water supply to potential contaminants identified during the inventory (susceptibility analysis).

In Idaho, ground-water source areas are delineated using three different methods, depending on the availability of hydrogeologic data and whether the system is transient or non-transient. These are the arbitrary fixed-radius method, the calculated fixed-radius method, and the refined method. The arbitrary fixed-radius method is used for non-community transient systems and involves drawing a circle with a fixed radius of 1,000 feet around a well. The calculated fixed-radius method is based on simplified calculations of 3-, 6-, and 10-year time-of-travel boundaries (i.e., capture zones) for Idaho's five generalized aquifer types. The radius for each time-of-travel boundary is determined for each generalized aquifer type by referencing pumping rate tables presented in Appendix E of the Idaho SWAP (IDEQ, 1999). Finally, the refined method for determining 3-, 6-, and 10-year time-of-travel boundaries involves computer modeling using site-specific data as input. The increased realism achieved by using site-specific data results in source water assessment areas that have less built-in conservatism and are often much smaller than those determined using the calculated fixed-radius method (IDEQ, 1999, p. E-10).

Assessment methods for ground water are important in Idaho because nearly 95 percent of the more than 2,100 PWSs rely on ground water as the source of their drinking water. These systems derive water from diverse and sometimes complex hydrogeologic settings. Graham and Campbell (1981) identified and described 70 regional hydrogeologic systems/provinces throughout the state (Figure 1). This report summarizes the source area delineation work that was performed for the Big Lost River Valley hydrologic province.

Figure 1.
Regional Hydrogeologic Systems in Idaho



1.2 Purpose and Objectives

The purpose of this report is to present the results of source area delineation work that was performed for the Big Lost River Valley hydrologic province under the purview of the Idaho Source Water Assessment Plan. The general objective is to apply the refined method to delineate the capture zones for public drinking water sources within the province. Specific objectives are to:

1. Identify and describe PWSs within the province.
2. Develop a conceptual model of the hydrogeology of the province.
3. Based on the conceptual model, determine model input and delineate capture zones for 3-, 6-, and 10-year travel times.
4. Perform a sensitivity analysis to evaluate model input uncertainty.
5. Incorporate factors of safety into the final capture zones to account for model input uncertainty.

1.3 Description of Public Water Systems

The Big Lost River Valley hydrologic province contains five PWSs, incorporating ten wells and one spring. The PWSs include those that provide water to Mackay City (#7190032), Antelope Creek Living Center (#7190001), Moore Water and Sewer Association (#6120022), Arco City (#6120001), and Butte City (#6120002), as shown in Figure 2. Most of the PWS wells tap water from the sand and gravel beds of the alluvial water table aquifer, yet some wells have screened intervals within basalt of the Snake River Plain aquifer. In some cases, wells in close proximity produce from different perched zones that overlie the deeper water table aquifer. The spring in the Mackay City area collects water from an outcrop of fractured rock in the foothills of the White Knob Mountains. Well completion details are provided in Table 1, and each PWS is described separately below.

Table 1. Summary Description of PWS Wells

PWS #	Well Designation	Year Installed	Avg. Pumping Rate (gal/day)	Total Depth (ft)	Screened/ Perforated Interval (ft-bgs)	Depth to Static Water Level (ft-bgs)+	Model
7190032	Well #1	1973	50,000	114	50-105	20	1
	Well#2	1990	28,000	100	38-98	18	1
	City Spring	1995	745,000	n/a	n/a	n/a	n/a
7190001	Well #1	1998	Unknown	130	112-128	36	2
6120022	Well #1	1969	37,700	174	125-171	15	3
	Well #2	1969		140	100-140	17	3
	Well #3	1991		140	86-138	5	3
6120001	Fill Station	1984	1,200,000	215	198-214	34	4
	Water St.	1992		660	540-580, 620-660	515	5
	Park	1962		250	209-242	133	6
6120002	Well #1	1960	9,000	475	461-475	395	7

+ Static water levels obtained from well logs

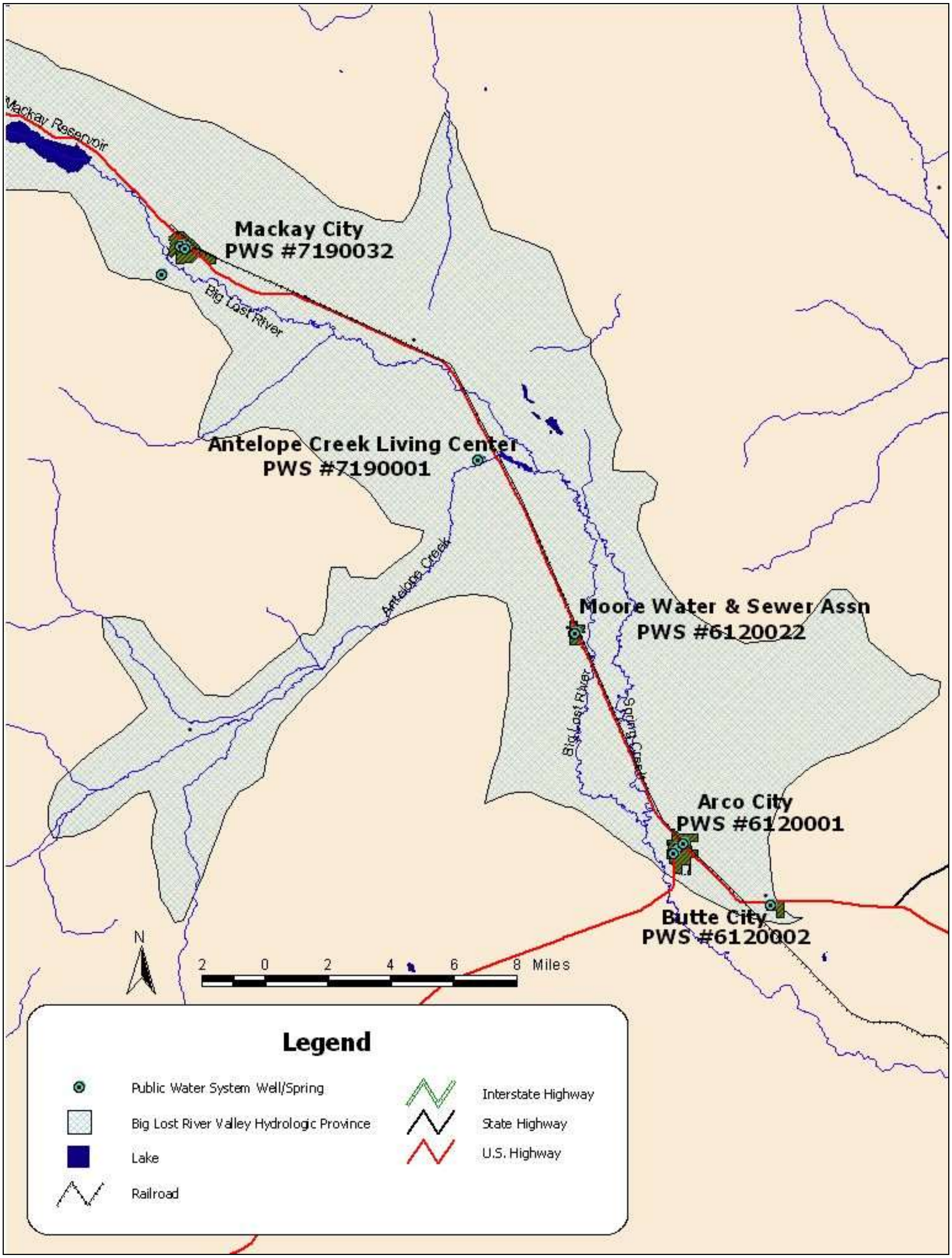


Figure 2. Public Water Systems in the Big Lost River Valley Hydrologic Province

1.3.1 PWS #7190032 – Mackay City

The Mackay City PWS comprises two wells and a spring (Figure A-1). The State of Idaho Public Water Supply Inventory Report (IDEQ, 1996) indicates that the PWS has 370 connections. The PWS serves a population of 620, according to the owner/operator (WGINT, 2000a).

Well #1 was completed in 1973 with 12-inch-diameter steel casing extending to its total depth of 114 feet. The screened interval is from 50 to 105 feet. The average volume of water pumped during a 24-hour period is 50,000 gallons (WGINT, 2000a). The peak pumping rate is 550,000 gal/day.

Well #2 was constructed in 1990 with 10-inch-diameter steel casing extending to its total depth of 100 feet. The casing is perforated from 38 to 98 feet. A 30-hp submersible pump is currently producing at an average rate of 28,000 gal/day (WGINT, 2000a). The peak volume of water pumped during a 24-hour period is 456,000 gallons.

The spring is located about 0.5 mile west of the city limit in the foothills of the White Knob Mountains. The spring issues from an outcrop of fractured rock and is channeled to an enclosed concrete structure. The structure has a locked access hatch, screened vent, drain pipe, and a 10-inch discharge line. The average flow rate is 745,000 gal/day (8.62 ft^3/sec), and the peak flow rate is 1,080,000 gal/day. Using the flow rate classification scheme developed by Meinzer (1923), this is a spring of third magnitude (EPA, 1977, p.3). The spring protection zone was not evaluated as part of the Big Lost River Valley hydrologic province because the water is not produced from the valley-fill aquifer.

1.3.2 PWS #7190001 – Antelope Creek Living Center

The Antelope Creek Living Center PWS is a single-well system (Figure A-2). The most recent Sanitary Survey Report (Adams, 1996) indicates that this PWS has one connection and serves a population of 43.

The well was constructed in a valley-fill aquifer and completed with 6-inch-diameter casing. The depth of the well is 130 feet below ground surface (ft-bgs). The screened interval is between 112 and 128 ft-bgs. The driller’s log indicates that the aquifer is a sandy gravel formation overlain by an 18-foot-thick layer of brown clay. The driller’s log also indicates that the static water level is above the depth of water first encountered during drilling, suggesting that the aquifer is confined by the clay layer. The production rate is unknown.

1.3.3 PWS #6120022 – Moore Water and Sewer Association

The Moore Water and Sewer Association PWS comprises three wells (Figure A-3). The most recent Sanitary Survey Report (Scott, 2000) indicates that the PWS has 118 connections and serves a population of 228.

The wells were completed in an unconfined valley-fill aquifer comprised of sand and gravel. Wells #1 and #2 are 12 inches in diameter and are 174 and 140 feet deep, respectively. Well screen spans the interval from 125 to 171 ft-bgs for Well #1 and 100 to 140 ft-bgs for Well #2. Well #3 is 8 inches in diameter, 140 feet deep, and has well screen between 86 and 138 ft-bgs. A brown clay layer between 78 and 86 ft-bgs was identified on the driller’s log for Well #3 but was not noted on the logs for Wells #1 and #2.

All three wells are operative with a combined average pumping rate of 37,700 gal/day. The peak volume of water pumped during a 24-hour period is 87,000 gallons.

1.3.4 PWS #6120001 – Arco City

The Arco City PWS comprises three wells (Figure A-4). The most recent Sanitary Survey Report (Stewart, 1999) indicates that the PWS has 580 metered connections and serves a population of 1,000. Large differences in the static water levels indicate that each well produces from a different aquifer (see Table 1).

The Fill Station well was completed to a depth of 215 feet with perforated casing between 198 and 214 ft-bgs. The depth to water on the driller's log is only 34 feet, indicating that the production zone is a perched aquifer.

The Water Street well was completed to a depth of 660 feet, with well screen spanning the intervals from 540 to 580 ft-bgs and 620 to 660 ft-bgs. The static water level is approximately 515 ft-bgs. A pumping rate of 883 gal/min results in approximately 3 feet of drawdown (Stewart, 1999).

The Park well was completed to a depth of 250 feet. It has a 20-inch-diameter casing with well screen between 209 and 242 ft-bgs. The static water level is 133 ft-bgs. Stewart (1999) indicates a well production of 1,500 gal/min with approximately 10 feet of drawdown.

The average water usage for the city is 1.2 million gal/day; the maximum usage is 2.4 million gal/day (Stewart, 1999). Pumping from the three area wells is assumed to be 10 percent for the Fill Station well, 35 percent for the Water Street well, and 55 percent for the Park well based on the pump capacities (Stewart, 1999) and a telephone interview with the Arco City well operator (Lonnie Woodbridge, July 19, 2001).

1.3.5 PWS #6120002 – Butte City

The Butte City PWS is a single-well system (Figure A-4). The State of Idaho Public Water Supply Inventory Report (IDEQ, 2000) indicates that the PWS has 38 connections and serves a population of 59.

The well was completed with 16-inch-diameter casing to a depth of 475 feet. Well screen spans the interval between 461 and 475 feet. The average volume of water pumped during a 24-hour period is 9,000 gallons, while the maximum production rate is 18,525 gal/day.

1.4 Hydrogeologic Conceptual Model

The Big Lost River basin occupies approximately 1,400 square miles at the northern side of the Eastern Snake River Plain (Szczepanowski, 1982). The basin is northwest to southeast trending and is bounded on the east by the Lost River Range and on the west by the White Knob Mountains. The adjacent mountains are composed of a sedimentary sequence of limestone, dolomite, quartzite, sandstone, shale, and argillite. Granitic rock occurs in some places within the sedimentary units, while volcanic materials cover an extensive area at higher elevations. Basalt from the Snake River Plain is also found at the surface in the south end of the Big Lost River basin.

The Big Lost River flows through the axis of the valley and is controlled by the Mackay Dam. An examination of the historical stream flow data (USGS, 2000a) indicates that base flow of the river near Mackay is relatively constant during the year, except during the summer months when the flow rate is increased. It is believed that the Big Lost River stage controls the regional ground-water levels. Flow in the Sharp Ditch (USGS, 2000b) along the eastern edge of the foothills is intermittent and occurs only in the summer months when irrigation demand is high.

The valley-fill sediments are present in two forms: cemented and unconsolidated. Calcite cement binds together fragments of sandstone, quartzite, and limestone of the old colluvial fans. The unconsolidated materials are composed of clay- to boulder-size particles and range greatly in degree of sorting. The alluvial fill varies from 2,000 to 3,000 feet thick in the Barton Flat area to over 5,000 feet east of Mackay (Szczepanowski, 1982, p. 5).

The primary source of water to the alluvial aquifer is precipitation at higher elevations that infiltrates through fractures in the bedrock. Some of the water is discharged to streams, and some continues downslope entering the valley alluvium. Numerous streams lose all their flow to the highly permeable colluvial fans found near the valley floor. Other sources of recharge include precipitation on the valley floor, irrigation, and leakage from canals. Annual precipitation within the basin is elevation-dependent and varies from 10 to 45 inches (Szczepanowski, 1982, p. 3).

Natural discharge of ground water occurs as gains to the Big Lost River, as underflow leaving the basin south of Arco, and as evapotranspiration where the water table is at or near the land surface.

The water table ranges in elevation from about 6,300 feet above mean sea level (ft msl) near Chilly to 5,200 ft msl south of Arco (Briar et al., 1996). Ground-water flow direction generally follows the valley centerline toward the south and southeast. The valley fill aquifer generally is unconfined, although perched and artesian conditions are known to occur. Localized perched and artesian zones developed as the result of widely scattered lenses of low-permeability materials (Szczepanowski, 1982, p. 6).

Estimates of transmissivity, based on an aquifer test in the Lower Big Lost River Valley between Antelope Creek and Butte City (Bassick and Jones, 1992), range from 61,000 to 330,000 ft^2/day, with a geometric mean of 144,535 ft^2/day. Analyses of the test data indicated that the bedrock/ valley-fill contact functions as a barrier boundary.

2.0 CAPTURE ZONE MODELING

2.1 Method

The analytic element model WhAEM2000 (Kraemer et al., 2000) was used to delineate the 3-, 6-, and 10-year capture zones for PWS wells located within the Big Lost River Valley hydrologic province. A separate model was developed for each PWS, with the exception of the Arco City PWS, which required three models because water is produced from three different aquifers. The significant elevation change in the valley is the primary reason for simulating the PWS wells in separate models; the WhAEM2000 program allows for specification of only a single base elevation and aquifer thickness. Modeling these well systems in subdivided hydrologic areas also allows for the use of site-specific model input.

The method used to delineate hydraulic capture zones for the Big Lost River Valley hydrologic province contains four main elements:

1. Model Input Determination (Section 2.2) – Model input was determined with reference to the hydrogeologic conceptual model based on literature review, well logs, and available aquifer test data. A best estimate of transmissivity was determined for selected wells based on analysis of specific capacity data assuming that the wells are 100 percent efficient (i.e., no well loss). Hydraulic conductivity was then calculated by assuming that the open interval is equivalent to the aquifer thickness. These estimates were then compared with published estimates to make sure that the specific capacity-derived estimates were reasonable.

2. Model Calibration (Section 2.3) – Model boundaries were assigned based on the hydrogeologic conceptual model and adjusted as necessary and reasonable to best replicate observed water-level measurements. Goodness of fit for the various model runs was determined by calculating the residual sum of squares (Macneal, 1992) and the root mean squared error (Rafai et al., 1998). The base case or “calibrated” model run was determined by selecting the run with the lowest residual sum of squares.

3. Sensitivity Analysis (Section 2.4) – Input properties for the base case run were varied to evaluate the effect of model input uncertainty on capture zone geometry.

4. Factor of Safety Determination (Section 2.5) – The outcome of the sensitivity analysis was used as the basis for determining an overall factor of safety for the final capture zone delineations. Although all of the inputs were evaluated during this process, the method of addressing model uncertainty reflects primarily the sensitivity of the results to the variability of the most uncertain parameter (i.e., hydraulic conductivity).

2.2 Model Input Determination

Model input is provided in Table 2. Determination of model input is discussed below for each simulation.

Table 2. Summary of Model Input

Model	Pumping Wells	Pumping Rate (ft^3/day)	Base K (ft/day)	Low K (ft/day)	High K (ft/day)	Effective Porosity	Base Elev. (msl)	Aquifer Thickness (ft)	Recharge (ft/day)
1	719003202 Well #1	10,026	767	242	2420	0.3	5,799	65	0.00023
	719003203 Well #2	5,615							
2	7190001 Well #1	1,543	1419	449	4490	0.3	5,484	16	0
3	612002201 Well #1	2,520	256	81	810	0.3	5,299	46	0.00018
	612002202 Well #2	2,520							
	612002203 Well #3	2,520							
4	612000106 Fill Station	16,043	741	234	2340	0.3	5,111	16	0.00009
5	612000105 Water St.	33,235	920	291	2909	0.15	4,662	80	0
6	612000101 Park	57,754	920	291	2909	0.3	5,072	25	0
7	612000201 Well #1	1,805	133	42	420	0.3	4,841	14	0

2.2.1 PWS #7190032 – Mackay City

The Mackay City PWS consists of two pumping wells on the east side of the Big Lost River and a spring on the west side of the river. Lithologic logs of Wells #1 and #2 indicate that the aquifer is unconfined with sand, gravel, and a mixture of sand, gravel, and clay. The Idaho Wellhead Protection Plan (IDEQ, 1997, Appendix A) presents transmissivity estimates of 47,100 ft^2/day for Well #1 and 48,700 ft^2/day for Well #2, based on analysis of specific capacity data. The equivalent hydraulic conductivities are 725 and 812 ft/day, respectively, conservatively assuming that the aquifer thickness is equivalent to the screened interval. The geometric mean hydraulic conductivity value of 767 ft/day was used for simulating the base case aquifer conditions. The effective porosity is 0.3, which is the default value presented in Table F-3 of the Idaho Wellhead Protection Plan for unconsolidated alluvium (IDEQ, 1997, p. F-6). Base elevation of the aquifer is 5,799 ft msl (bottom of Well #1 screen), and the aquifer thickness is 65 feet. The pumping rates are 1.5 times the indicated average on the owner/operator response to the PWS questionnaire (WGINT, 2000a).

The areal recharge is 1 in./yr, based on an infiltration test conducted at the Idaho National Engineering and Environmental Laboratory by Cecil et al. (1992) that resulted in an infiltration rate of 0.4 in./yr. A higher infiltration rate was used because Mackay is located at a higher elevation and in an area with more precipitation and less evapotranspiration. A constant-head boundary was used to simulate the Big Lost River. Aquifer recharge along the bedrock/valley-fill contact was simulated using a constant-flux line sink backed by a no-flow boundary.

2.2.2 PWS #7190001 – Antelope Creek Living Center

The Antelope Creek Living Center PWS is a single-well system. A lithologic log of the well indicates that an 18-foot-thick layer of brown clay confines the sand and gravel aquifer. Site-specific hydraulic properties could not be determined because no pumping test was performed at the well during construction. The best available estimates are based on analysis of a USGS aquifer test (Bassick and Jones, 1992) in the Lower Big Lost River Valley near Moore. The transmissivity estimates vary from 61,000 to 330,000 ft^2/day for an aquifer thickness of 100 feet. The high and low numbers of the range were used to calculate the geometric mean hydraulic conductivity (1,419 ft/day), which was used to simulate the base case aquifer conditions. The effective porosity is 0.3. Base elevation of the aquifer is 5,484 ft msl (bottom of Well #1 screen), and the aquifer thickness is the length of the screened interval (16 feet). The pumping rate is 11,540 gal/day (1,543 ft^3/day), which is 1.5 times the estimated actual rate of 7,697 gal/day. The actual pumping rate was estimated by multiplying the population served by the well (43) times the national per capita average of 179 gal/day (USGS, 1995, p. 1).

The areal recharge was set to 0 because the aquifer is confined. Recharge to the aquifer from the Blaine Canal and Antelope Creek near the well was ignored because of the presence of a confining layer. However, recharge in the upland area where the brown clay layer is absent controls the artesian pressure. Constant heads were used in the Antelope Creek upland area and along the Big Lost River channel. A constant-flux line sink backed by a no-flow boundary was used to simulate recharge along the valley margin.

2.2.3 PWS #6120022 – Moore Water and Sewer Association

The Moore Water and Sewer Association PWS consists of three pumping wells. Lithologic logs indicate that the aquifer is composed of sand and gravel with varying proportions of silt and clay. The aquifer in this area is generally unconfined. Specific capacity data from Well #1 and Well #2 were analyzed (see Attachment B) using the method of Walton (1962, p. 12), yielding hydraulic conductivity estimates of 825 gal/day/ft^2 (110 ft/day) and 4,449 gal/day/ft^2 (595 ft/day). These site-specific results are lower than those obtained by Bassick and Jones (1992) but are considered representative because, based on the driller’s log, the sand and gravel aquifer in this area has a significant proportion of silt and clay. The geometric mean hydraulic conductivity value (256 ft/day) was used for simulating the base case aquifer conditions. Base elevation of the aquifer was set at 5,299 ft msl (bottom of Well #1 screen), while the aquifer thickness is the screened interval thickness of 46 feet. The pumping rates are based on the owner/operator response to the PWS questionnaire (WGINT, 2000b).

The areal recharge is 0.8 in./yr. Constant-flux line sink boundary conditions were used along the Big Lost River channel. A constant-flux line sink backed by a no-flow boundary was used to simulate recharge along the valley margin.

2.2.4 PWS #6120001 – Arco City

The Arco City PWS consists of three pumping wells in close proximity. Capture zones in these three wells were analyzed separately using the WhAEM2000 model because lithologic logs and static water levels indicate that the wells produce water from three different aquifers. The area is highly heterogeneous with sand and gravel and localized clay lenses overlying the basalt bedrock. The Fill Station well is screened in a gravel layer that has a static water level of 5,496 ft msl. The Water Street well is screened within a fractured basalt formation that has a static water level of 5,008 ft msl, while the Park well is screened in a gravel layer that has a static water level of 5,387 ft msl.

Specific capacity data from the Fill Station well were analyzed using the method of Walton (1962, p. 12). The calculation (Attachment B) yields a hydraulic conductivity estimate of 5,543 gal/day/ft^2 (741 ft/day) for the gravel formation. A transmissivity estimate of 22,993 ft^2/day (IDWR, 1997, Table F-1) was used as the basis for calculating the hydraulic conductivity for the Park well simulation. This hydraulic conductivity value was also used as the basis for the Water Street well model, based on a similar pumping rate. The effective porosity is 0.3 for the alluvial systems and 0.15 for the basalt system. Base elevations of the three water zones were set at 5,111, 4,662, and 5,072 ft msl, respectively, for the Fill Station, Water Street, and Park wells, with aquifer thickness set equal to the thickness of screen intervals at 16, 80, and 25 feet, respectively. The pumping rate for each well was based on the average daily volumes discussed earlier.

The areal recharge (0.4 in/yr.) is based on an infiltration test conducted at the INEEL (Cecil et al., 1992). A constant-head boundary was used to represent the Big Lost River channel. A constant-flux line sink backed by a no-flow boundary was also used to simulate aquifer recharge along the valley margin.

2.2.5 PWS #6120002 – Butte City

The Butte City PWS is a single-well system. The lithologic log for the well indicates that the aquifer is a sand and gravel interbed that is confined by an overlying dense basalt layer. Specific capacity data were analyzed using the method of Walton (1962, p. 12). The calculation (see Attachment B) yields a hydraulic conductivity estimate of 992 gal/day/ft^2 (133 ft/day). This hydraulic conductivity value was used for simulating base case aquifer conditions. The effective porosity is 0.3. Base elevation of the aquifer is 4,841 ft msl (bottom of well screen), and the aquifer thickness is the perforated screen interval (14 feet). The pumping rate 1.5 times the reported average rate of usage.

The areal recharge is 0 because the aquifer is confined. A constant-head boundary was used to represent the Big Lost River. A constant-flux line sink backed by a no-flow boundary was also used to simulate aquifer recharge along the valley margin.

2.3 Model Calibration

USGS monitoring wells (Brennan et al., 1999), Idaho Department of Water Resources statewide monitoring wells (IDWR, 2001), and PWS wells were used as simulation test point wells to evaluate the goodness of fit of calibration runs. The test point well information is presented in Table 3. The hydraulic head in each USGS monitoring well was set to the water levels measured in September 1999 (Brennan et al., 1999). Statewide monitoring wells were set to water levels measured between

1990 and 1999. The water levels, at the time of completion, in PWS wells were used to provide an additional test point well for models 4 through 7. An overall, non-quantitative assessment of model reasonableness was made by comparing the model-predicted flow pattern with published potentiometric surface maps (Bassick and Jones, 1992; and Briar et al., 1996).

Table 3. Summary of Test Point Wells

Model #	Well	Total Depth (ft)	Screened/ Perforated Interval	Date of Measurement	Water Level (ft msl)	Reference
1	07N 24E 07CCB3	50	18-48	1997	5980.3	SMN
1	07N 24E 26CDD1	101	Open	1999	5,866.5	SMN
1	07N 25E 31ABB1	120	4-120	1994	5,788.7	SMN
2	06N 25E 03AAA1	91.7	Unknown	09-08-99	5,689	USGS
2,3	05N 26E 05DCB1	260	60-260*	09-07-99	5,539	USGS
2,3	06N 25E 36DBB1	80	Open	1999	5,587.9	SMN
3	05N 26E 28BBB1	162	40-162	1990	5,472.1	SMN
3	05N 26E 34CCA1	160	30-150	1996	5,343.7	SMN
4	04N 26E 26DCD1	136	Unknown	09-07-99	5292	USGS
4	Fill Station Well	215	198-214	1984	5288	Driller's Log
5	Park Well	660	540-580, 620-660	1992	4817	Driller's Log
6	04N 26E 32CBB1	253	205-253*	09-07-99	5171	USGS
6	Water Street Well	250	209-242	1962	5289	Driller's Log
7	Butte City Well	475	461-475	1960	4936	Driller's Log
7	03N 27E 10BAB2	400	Unknown	1996	4942	SMN

* Open hole construction; no well screen or casing
SMN – Statewide Monitoring Network (Neeley, 2001)
USGS – Brennan et al., 1999

The graphical output from selected calibration runs is presented in Attachment C and discussed below for each model.

2.3.1 PWS #7190032 – Mackay City

Initial model input provided a good fit at test point well locations, despite not simulating aquifer recharge at the bedrock/valley-fill contact (p. C-1). Recharge along the contact on the eastern margin of the basin was represented in run 2 by adding a constant-flux line sink (p. C-2). The added aquifer recharge of 50 ft^2/day, based on 8 inches of annual precipitation infiltration applied over the catchment east of the constant-flux line sink, resulted in a slightly poorer fit and an approximate 9-degree shift northeast in the flow path orientation. A large flux value was chosen to evaluate the model's sensitivity to recharge along the bedrock/valley-fill contact and to account for the larger amounts of precipitation received at higher elevations. Run 2 was selected as the base case based on an average head difference of less than 2 feet and the more realistic representation of aquifer recharge.

2.3.2 PWS #7190001 – Antelope Creek Living Center

The initial model input provided a good fit at test point well locations and a low average head difference (p. C-3). Two no-flow boundaries were added in run 2 to represent the low-permeable bedrock comprising Leslie Butte and a smaller unnamed butte upgradient of the Antelope Creek well. The no-flow boundaries resulted in a more realistic prediction of pathlines winding around the butte to the west (p. C-4). The White Knob constant-flux line sink and no-flow boundary was moved slightly eastward in run 3, resulting in the predicted pathlines moving to the east side of the butte and terminating at the Big Lost River (p. C-5). Model runs 2 and 3 were both used for capture zone delineation because both scenarios are equally viable.

2.3.3 PWS #6120022 – Moore Water and Sewer Association

The initial model input provided a good fit at test point well locations (p. C-6). Model run 2 (p. C-7) provided a better fit at test point well locations than run 1, which had the constant-flux line sinks along the basin's margin removed. The particle paths for run 2 were oriented 5 degrees east of those for run1. Run 2 was chosen as the base case model based on the least squares criterion.

2.3.4 PWS #6120001 – Arco City

The completion of wells in different aquifers made it inappropriate to use most of the USGS and statewide monitoring wells in the Arco area as test point wells. Only one or two test point wells were used to determine goodness of fit. Calibration resulted in water table gradients of 0.0033, 0.0040, and 0.0031 for the Fill Station, Water Street, and Park simulations, respectively. The modeled gradients are comparable to the gradient (0.0034) for the water table map presented in Bassick and Jones (1992) and to the topographic gradient (0.0035) estimated from a USGS 1:24,000 map of the Arco area.

Each model was run with and without recharge along the bedrock/valley-fill contact (pp. C-8 through C-13). Little difference was noted in the goodness of fit for any of the models. Particle path lengths and orientations were not significantly affected by the recharge along the valley margin. Run 2 was chosen as the base case for the Fill Station and Water Street well models based on the least squares criterion. Run 1 was chosen as the base case for the Park well model (p. C-12).

2.3.5 PWS #6120002 – Butte City

The calibration process for the Butte City model (pp. C-14 and C-15) was the same as for Arco City models. The topographic gradient in the vicinity of Butte City was estimated at 0.0011. The water table in the model was set by assignment of constant-head boundaries to reflect that gradient. Run 2 was selected as the base case based on the least squares criterion.

2.4 Sensitivity Analysis

A sensitivity analysis was performed to evaluate the effect of model input uncertainty for the Big Lost River Valley hydrologic province. Consideration was given to the hydrogeologic setting; to the density, source, quality, and variability of the data used to develop each model input; and to the theoretical dependence of the shape and extent of the capture zones on each of the model inputs. The latter was facilitated by referencing analytical solutions for the geometry of steady-state capture zones under homogeneous and isotropic conditions in a uniform flow field (Javandel and Tsang, 1986 and Gorelick et al., 1993).

2.4.1 Relative Uncertainty

The first step in the analysis was to consider the relative uncertainty of model inputs. Inputs to WhAEM that affect the geometries of time-dependent capture zones include boundary assignments, hydraulic conductivity (K), aquifer base elevation (z_0), aquifer thickness (b), effective porosity (n_e), the areal recharge rate (N), and the pumping rate (Q). While model results are sensitive to all of these inputs, the uncertainty and spatial variability associated with hydraulic conductivity is generally greater than all other inputs (with the possible exception of the areal recharge rate in an unconfined aquifer). This is illustrated by the fact that hydraulic conductivity is one of very few physical properties that takes on values ranging over 13 orders of magnitude (Freeze and Cherry, 1979, p. 28). The second column in Table 4 presents the assessed relative uncertainty associated with each of the inputs for the Big Lost River Valley capture zone delineations.

Table 4. Model Input Uncertainty

Input	Relative Uncertainty	Primary Effect on Capture Zone Geometry	Approach
Boundary Assignments	Moderate	Orientation	Adjusted as necessary and reasonable to minimize the sum of squares. Accounted for uncertainty via angular safety factor of $\pm 15°$.
Hydraulic Conductivity	High	Width and length	Accounted for uncertainty/heterogeneity by varying K over an order of magnitude. If the downgradient limit of the capture zone for a PWS well was 300 feet or less, a 200-foot buffer was added to the downgradient extent.
Aquifer Base Elevation	Low	N/A for pumping water levels above top of aquifer	Assumed bottom of open interval of the deepest well in each model.
Aquifer Thickness	Moderate	Width	Assumed average open interval based on probable anisotropy and to maintain conservatism in capture zone extent.
Effective Porosity	Moderate	Length	Assumed default value for aquifer medium.
Areal Recharge Rate	Moderate	Area (for a given hydraulic gradient)	Assumed zero for confined aquifer and used published values for unconfined aquifer.
Pumping Rate	Low	Width	Used multiplier of 1.5 to account for seasonal variations and near-term growth.

2.4.2 Theoretical Considerations

The second step in the sensitivity analysis was to develop an understanding of the theoretical effects of input variations on the geometry of the 3-, 6-, and 10-year capture zones. Consideration of the geometry of a steady-state capture zone under idealized conditions was used to facilitate this process. The idealized situation involves two-dimensional, uniform, steady flow toward a single well pumping at a constant rate from a homogenous, isotropic confined aquifer. Under these circumstances, the maximum width of the capture zone is directly proportional to the pumping rate (Q) and inversely proportional to the product of transmissivity (T=Kb) and the uniform hydraulic gradient (I) (see, for example, Gorelick et al., 1993, p. 128). Also, the distance from the well to the stagnation point at the downgradient limit of hydraulic capture is $Q/2\pi TI$, and the width of the capture zone along the line orthogonal to the natural hydraulic gradient at the well is Q/TI. In other words, increasing the pumping rate increases proportionally the width of a capture zone and the distance to the stagnation point, whereas increasing either the hydraulic conductivity or the aquifer thickness decreases the width and the distance to the stagnation point. Decreasing the transmissivity also reduces the relative impact of the regional hydraulic gradient on capture zone geometry, compared to the cone of depression caused by pumping. The net effect is to make the capture zone more circular with decreasing transmissivity and more elongated with increasing transmissivity.

Theoretical considerations also can be used to explain parameter sensitivity for time-dependent capture zones. For example, the length of time-dependent capture zones is increased by decreasing the effective porosity, since the well has to produce the same amount of water from a less porous medium. The effect of increasing hydraulic conductivity is to increase transmissivity, which thereby reduces capture zone width and increases capture zone length. Increasing aquifer thickness tends to decrease width in a similar manner but not increase length, since it also has the effect of increasing the amount of pore space. This last point is important because it illustrates that the two-dimensional capture zone geometry is more sensitive to hydraulic conductivity than to aquifer thickness.

2.4.3 Simulation

Finally, the effect of input variation was evaluated by simulation. Sensitivity was evaluated by making adjustments to the base case model input for model 3 (City of Moore) as noted in Table 5. Hydraulic conductivity was varied over an order of magnitude (i.e., base case K x $10^{\pm 0.5}$) to account for the higher uncertainty associated with this value. Porosity was varied over the range of values presented in the Idaho Wellhead Protection Plan for unconsolidated alluvium (IDEQ, 1997, p. F-6). Aquifer thickness and recharge were varied by ±50 percent.

Capture zone geometry was most sensitive to changes in the least certain parameter (hydraulic conductivity) and less sensitive to variations in aquifer thickness, areal recharge, and effective porosity (Attachment D, pp. D-1 through D-8). Decreasing the hydraulic conductivity by a half order of magnitude resulted in a slight shift of the particle paths to the east and a shorter capture zone (p. D-2). It also resulted in significant changes to the goodness of fit, as determined by comparing the sum of squares and root mean square error statistics. Increasing hydraulic conductivity resulted in only a minor shift in flow direction and significantly longer narrower flow paths (p. D-4). Varying effective porosity had no effect on the goodness of fit because the simulated hydraulics are steady state. Decreasing the hydraulic conductivity had the greatest impact on average head differences at test point well locations, followed closely by changes to areal recharge.

Table 5. Sensitivity Analysis

Model	Statistics	Base case	Hydraulic Conductivity x $10^{-0.5}$	Hydraulic Conductivity x $10^{0.5}$	Thickness x 0.5	Thickness x 1.5	Porosity = 0.20	Areal Recharge x 0.5	Areal Recharge x 1.5
Model 3 (City of Moore)	Sum of Squares	9.09	245.46	54.98	46.44	24.20	9.09	15.79	5.16
	Root Mean Square Error	1.51	7.83	3.71	3.41	2.46	1.51	1.99	1.14
	Average Head Difference for Test Point Wells	-1.16	4.63	-2.99	1.52	-2.05	-1.16	-1.76	-0.55
	Average Head Difference Model Run - Base Case	N/A	5.79	-1.83	2.68	-0.89	0.00	-0.61	0.61

2.5 Factor of Safety

The outcome of the sensitivity/uncertainty analysis was used as the basis for determining an input variation factor of safety for the final capture zones. Based on these results, literature review, and professional judgment, the input of least certainty (hydraulic conductivity) was varied over an order of magnitude (i.e., best estimate times $10^{\pm 0.5}$) for the Mackay, Moore, and Butte models and a half order of magnitude (i.e., best estimate times $10^{-0.5}$) for the remaining models to account for uncertainty in aquifer properties. Hybrid time-dependent capture zones were then constructed for each well based on the predicted pathlines for the low-, base-, and high-conductivity scenarios described above. The pumping rate multiplier of 1.5 (see Section 2.2) provided an additional measure of conservatism to the capture zones for each model. A fixed 200-foot buffer was added to a capture zone if the downgradient extent was 300 feet or less from the PWS well. The buffer was added to provide a factor of safety in the natural downgradient direction.

The hybrid capture zones were rotated about the well(s) to account for flow direction uncertainty. The flow direction factor of safety conceptually accounts for uncertainty in model boundaries, as well as seasonal variations in flow direction. By agreement with IDEQ technical representatives, the flow direction factor of safety for the Big Lost River Valley hydrologic province is ±15 degrees from the orientation of the base case. For comparison, the Wyoming Wellhead Protection Guidance (WDEQ, 1997) suggests an angular safety factor of ±14 degrees, while the Oregon Wellhead Protection Program Guidance Manual (Stewart and Nelson, 1996) suggests a factor of ±25 degrees when the hydrogeologic conceptual model is based on site-specific data. In addition to the low- and base-conductivity scenarios, predicted pathlines from calibration runs 1 and 2 were used in the development of hybrid capture zones for the Antelope Creek model due to flow direction uncertainty around Leslie Butte.

In summary, the safety factor for the Big Lost River Valley hydrologic province includes an input variation component to account for parameter uncertainty, a pumping rate multiplier to account for near-term growth and/or seasonal variations in discharge, an angular component to account for flow direction uncertainty, and in some cases, a fixed-distance buffer to provide conservatism in the downgradient direction. Based on available data, this treatment of model uncertainty is considered reasonable but not overly conservative.

2.6 Results

The final capture zones for each simulation are described below and presented in Attachment E.

2.6.1 PWS #7190032 – Mackay City

The final hybrid capture zones fill the valley located north of the PWS wells to Mackay Reservoir between the Big Lost River on the west and the Lost River Range on the east (Figure E-1). Hybrid capture zone boundaries are terminated on the east where they intersect the 6,000-foot contour and on the west at the Big Lost River. Each of the resulting 4.3-mile-long capture zones encompasses an approximate area of 2 square miles (1.4 square miles for the 0- to 3-yr travel times and 0.6 square mile for the 3- to 6-yr travel times).

2.6.2 PWS #7190001 – Antelope Creek Living Center

The extent of the final capture zone for the Antelope Creek Living Center well is limited to the west by the White Knob Mountains, in the center by Leslie Butte, to the east by the Lost River Range, and to the north by the Big Lost River (Figure E-2). The capture zone to the west of Leslie Butte extends approximately 8.7 miles. The capture zone east of Leslie Butte terminates within the 3-year travel time at the Big Lost River near the Darlington Sinks. The total area encompassed by the capture zone is 11 square miles.

2.6.3 PWS #6120022 – Moore Water and Sewer Association

The final hybrid capture zones for the Moore Water and Sewer Association wells are northwest trending and are approximately 7.6 miles in length (Figure E-3). The capture zones terminate at the base of the White Knob Mountains and at the Big Lost River. The average areas of the 0- to 3-, 3- to 6-, and 6- to 10-year capture zones are 1, 3, and 6 square miles, respectively.

2.6.4 PWS #6120001 – Arco City

Final hybrid capture zone delineations for Arco City vary in length from 5 to 11 miles (Figure E-4). The eastern edge of each capture zone terminates at the base of the Lost River Range northeast of Arco. The average area for the 0- to 3-, 3- to 6-, and 6- to 10-year travel times are 1, 3, and 7 square miles, respectively, which combine for a total area of 13 square miles.

2.6.5 PWS #6120002 – Butte City

The shallow gradients and relatively low hydraulic conductivity values used in the Butte City model resulted in a 0.8-mile-long northwest trending capture zone (Figure E-4). The 10-year capture zone covers a total area of 0.25 square mile.

3.0 REFERENCES

Adams, S., 1996, Sanitary Survey Report, City of Darlington, Custer County, Idaho, Idaho Department of Health and Welfare, Division of Environmental Quality, 4 p.

Bassick, M.D., and M.L. Jones, 1992, Aquifer-Test Results, Direction of Ground-Water Flow, and 1984-90 Annual Ground-Water Pumpage for Irrigation, Lower Big Lost River Valley, Idaho. U.S. Department of Interior – U.S. Geological Survey.

Brennan, T.S., A.M. Campbell, A.K. Lehmann, and I. O'Dell, 1999, Water Resources Data Idaho Water Year 1999, Volume 1. Great Basin and Snake River Basin above King Hill, Water-Data Report ID-99-1, 392 p.

Briar, D., S.M. Lawlor, M.A.J. Stone, D.J. Parliman, J.L. Schaefer, and D. Kendy, 1996, Ground-Water Levels in Intermontane Basins of the Northern Rocky Mountains, Montana and Idaho. U.S. Department of Interior – U.S. Geological Survey.

Cecil, L.D., J.R. Pittman, T.M. Beasley, R.L. Michel, P.W. Kubik, P. Sharma, U. Fehn, and H. Gove, 1992, Water Infiltration Rates in the Unsaturated Zone at the Idaho National Engineering Laboratory Estimated from Chlorine-36 and Tritium Profiles, and Neutron Logging, Y.K. Kkharak and A.S. Meest, eds., Proceedings of the 7th International Symposium on Water Rock Interaction – WRI –7, Park City, Utah.

EPA – See United States Environmental Protection Agency

Freeze, R.A., and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Inc., 604 p.

Gorelick, S.M., R.A. Freeze, D. Donohue, and J.F. Keely, 1993, Groundwater Contamination: Optimal Capture and Containment, Lewis Publishers, 385 p.

Graham, W.G., and L.J. Campbell, 1981, Groundwater Resources of Idaho, Idaho Department of Water Resources, 100 p.

Idaho Department of Environmental Quality, 2000, State of Idaho Public Water Supply Inventory Form, Pocatello Regional Office, Butte City Public Water System.

Idaho Department of Water Resources, 1999, Feasibility of Large Scale Managed Recharge of the Eastern Snake River Plain Aquifer System, Idaho Department of Water Resources, 248 p.

Idaho Department of Water Resources, 2001, Idaho Statewide Ground Water Quality Monitoring Program Wells Database.

Idaho Division of Environmental Quality, 1996, State of Idaho Public Water Supply Inventory Form, Idaho Falls Regional Office, Mackay City Public Water System.

Idaho Division of Environmental Quality, 1997, Idaho Wellhead Protection Plan, Idaho Wellhead Protection Work Group, February.

Idaho Division of Environmental Quality, 1999, Idaho Source Water Assessment Plan, October, 39 p.

IDEQ – see Idaho Division of Environmental Quality

IDWR – see Idaho Department of Water Resources

Javandel, I., and C.F. Tsang, 1986, Capture-Zone Type Curves: A Tool for Aquifer Cleanup, Ground Water, vol. 24, no. 5, p. 616-625.

Kraemer, S.R., H.M. Haitjema, and V.A. Kelson, 2000, Working with WhAEM2000 Source Water Assessment for a Glacial Outwash Well Field, Vincennes, Indiana, U.S. Environmental Protection Agency, Office of Research, EPA/600/R-00/022, 50 p.

Macneal, R.W., 1992, Estimating Aquifer Properties in Analytic Element Models, Proceedings of the 1992 Solving Ground Water Problems with Models, February 11-13, p. 173-185.

Meinzer, O.E., 1923, Outline of Groundwater Hydrology: U.S. Water-Supply Paper 494, U.S. Geological Survey, Reston, Virginia, 71p.

Rafai, H.S., C.J. Newell, J.R. Gonzales, S. Dendrou, B. Dendrou, L. Kennedy, and J.T. Wilson, 1998, User's Manual for BIOPLUME III - Version 1.0, National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 282 p.

Scott, S., 2000, Sanitary Survey Report, City of Moore, Butte County, Idaho, Idaho Department of Health and Welfare, Division of Environmental Quality, 4 p.

Stewart, E., 1999, Sanitary Survey Report, City of Arco, Butte County, Idaho, Idaho Department of Health and Welfare, Division of Environmental Quality, 4 p.

Stewart, S., and D. Nelson, 1996, Oregon Wellhead Protection Program Guidance Manual, Department of Environmental Quality and Oregon Health Division, 23 p.

Szczepanowski, S.P., 1982, Review of Ground-Water Conditions in the Big Lost River Valley, Idaho Department of Water Resources. Idaho.

United States Environmental Protection Agency, 1997, Investigation of Hydrogeologic Mapping to Delineate Protection Zones Around Springs, Report of Two Case Studies, Office of Research and Development, Washington DC EPA/600/R-97/023.

United States Geological Survey, 1995, Trends in Water Use, 1950-1995, http://water.usgs.gov/watuse/pdf1995/pdf/trends.pdf, 5 p.

United States Geological Survey, 2000a, Historical Streamflow Daily Values for Big Lost River Below Mackay Reservoir Near Macky, Idaho, http://waterdata.usgs.gov/nwis-w/ID/?statnum=13127000.

United States Geological Survey, 2000b, Historical Streamflow Daily Values for Sharp Ditch Near Mackay, Idaho, http://waterdata.usgs.gov/nwis-w/ID/?statnum=13126500.

USGS – see United States Geological Survey

Walton, W.C., 1962, Selected Analytical Methods for Well and Aquifer Evaluation, Illinois State Water Survey, Department of Registration and Education, Bulletin 49, 81 p.

Washington Group International, Inc., 2000a, Idaho Department of Environmental Quality Source Water Assessment Program Public Water System Questionnaire, PWS No. 7190032.

Washington Group International, Inc., 2000b, Idaho Department of Environmental Quality Source Water Assessment Program Public Water System Questionnaire, PWS No. 7190022.

WDEQ – see Wyoming Department of Environmental Quality

WGINT – see Washington Group International, Inc.

Wyoming Department of Environmental Quality, 1997, Wyoming's Wellhead Protection Program Guidance Document, http://www.wrds.uwyo.edu/wrds/deq/whp/whpcover.html

Attachment A
Location of PWS and Test Point Wells

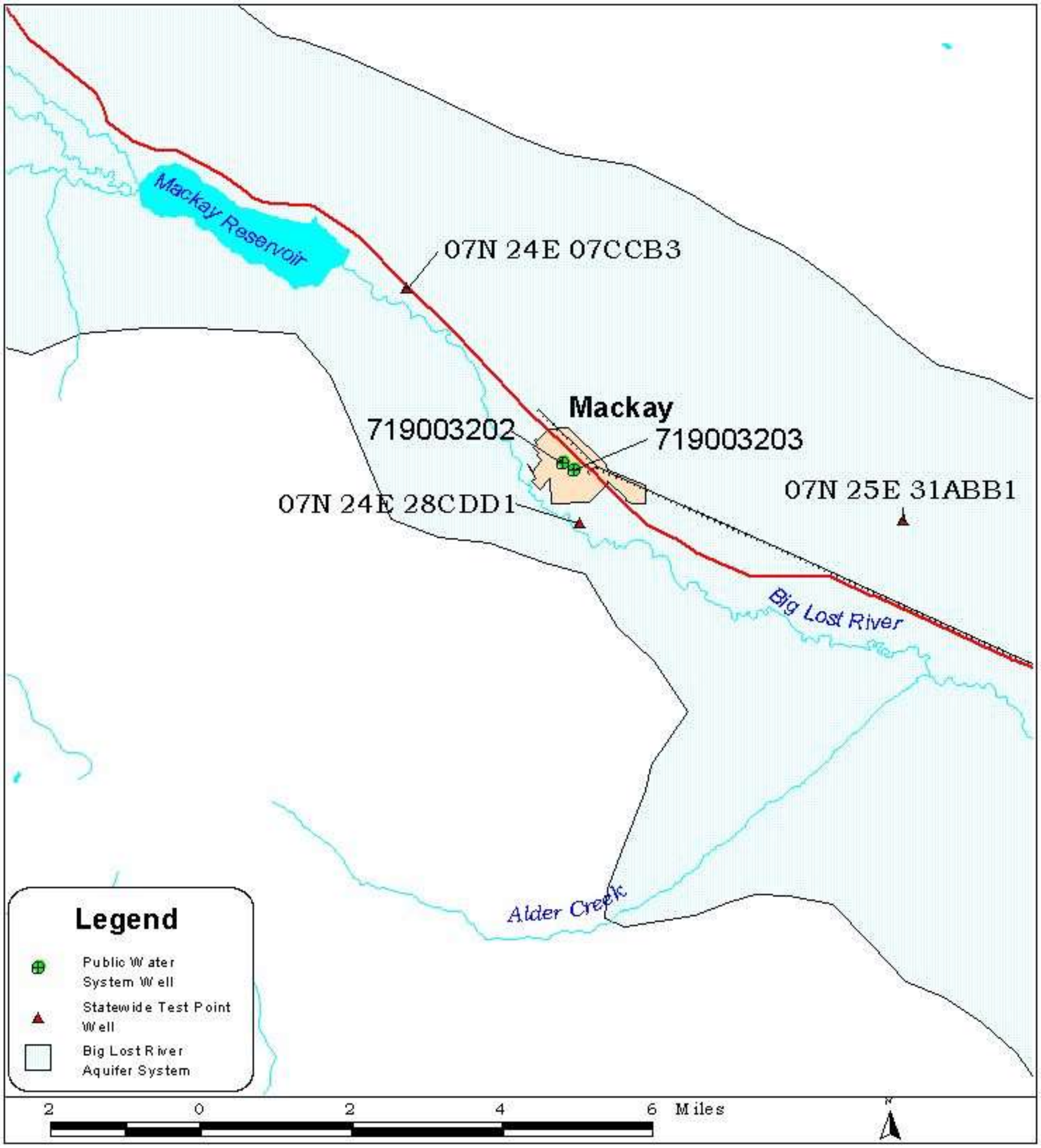


Figure A-1. Mackay City PWS Wells.

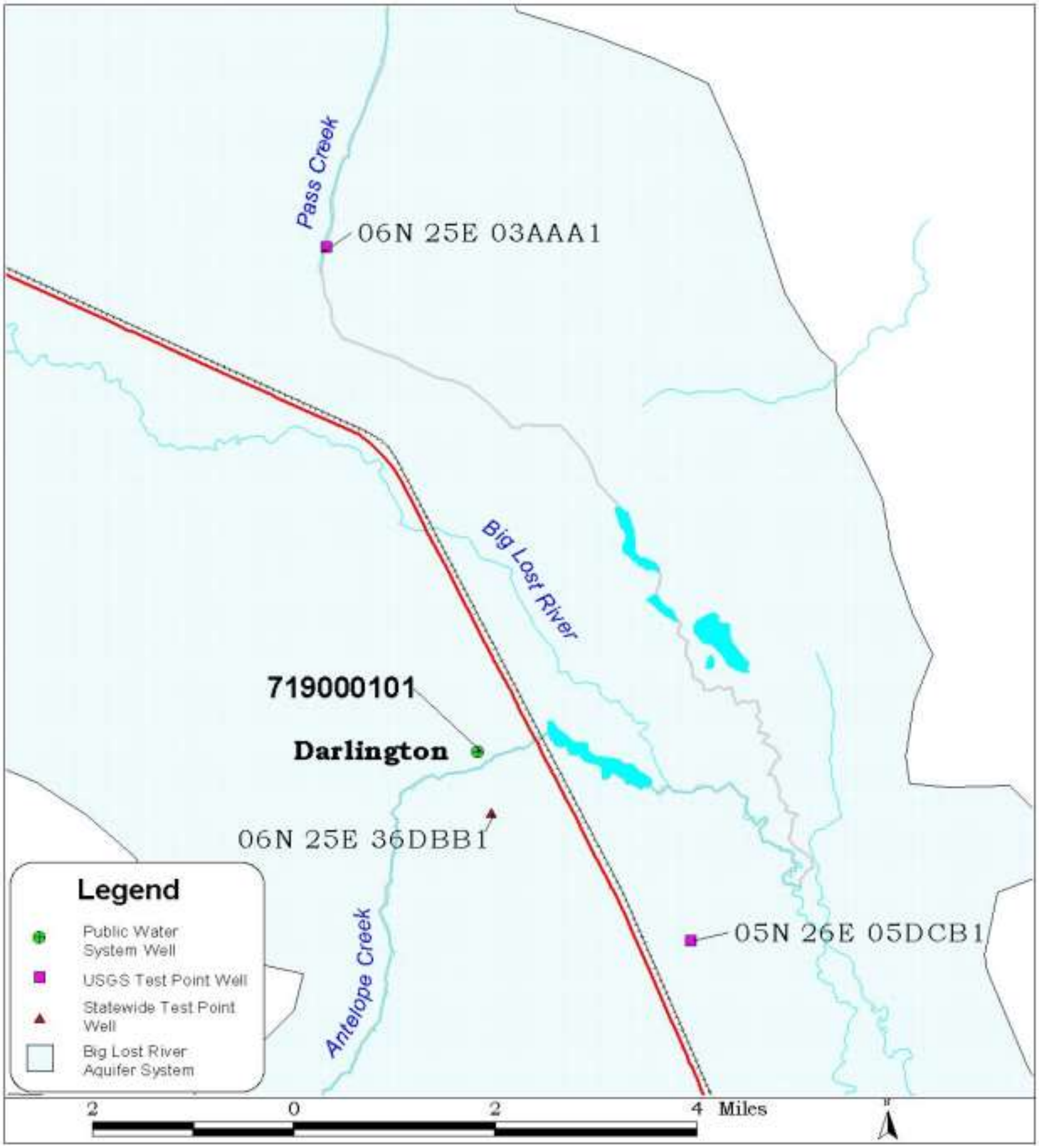


Figure A-2. Antelope Creek Living Center PWS Well.

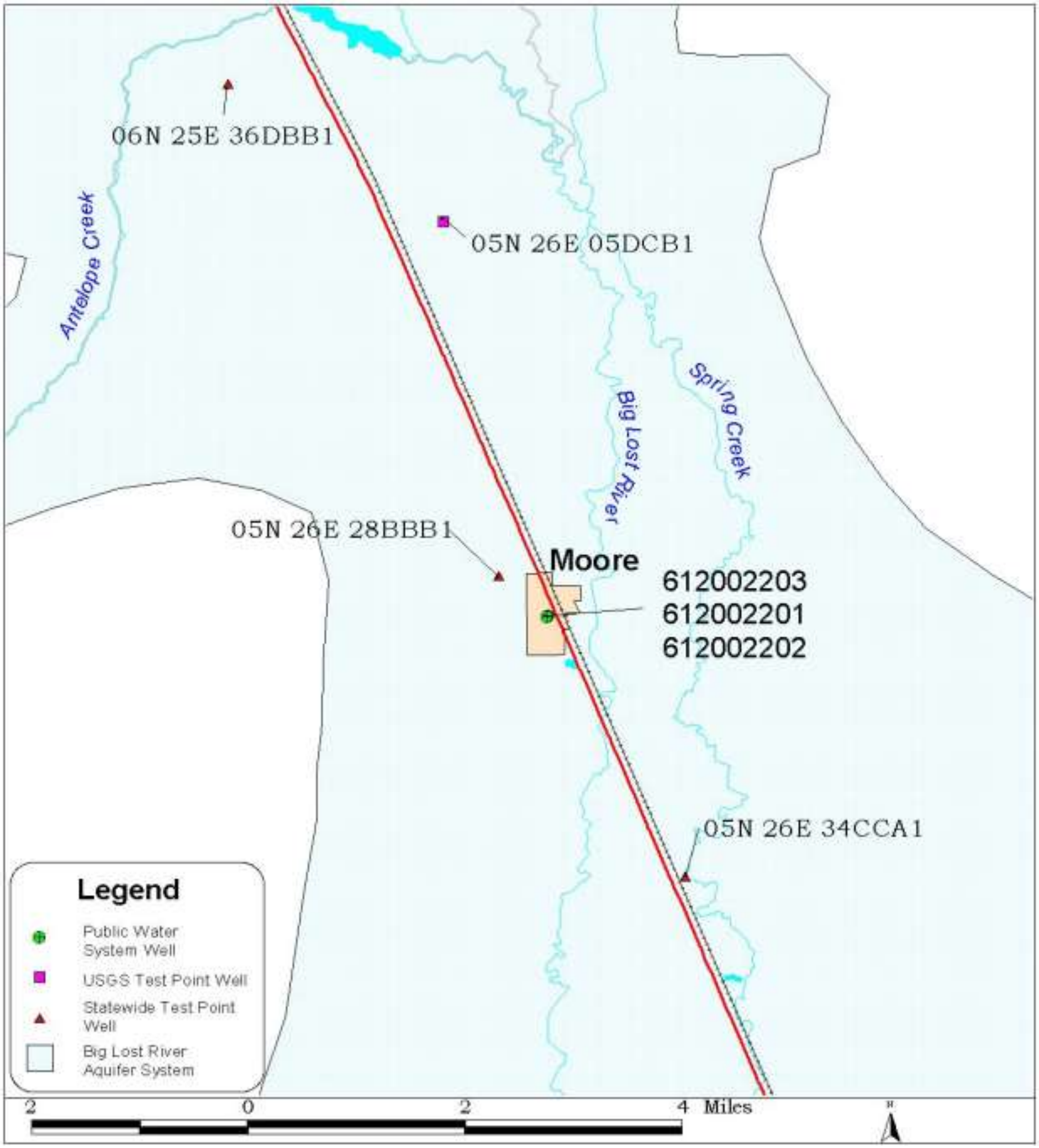


Figure A-3. Moore City PWS Wells.

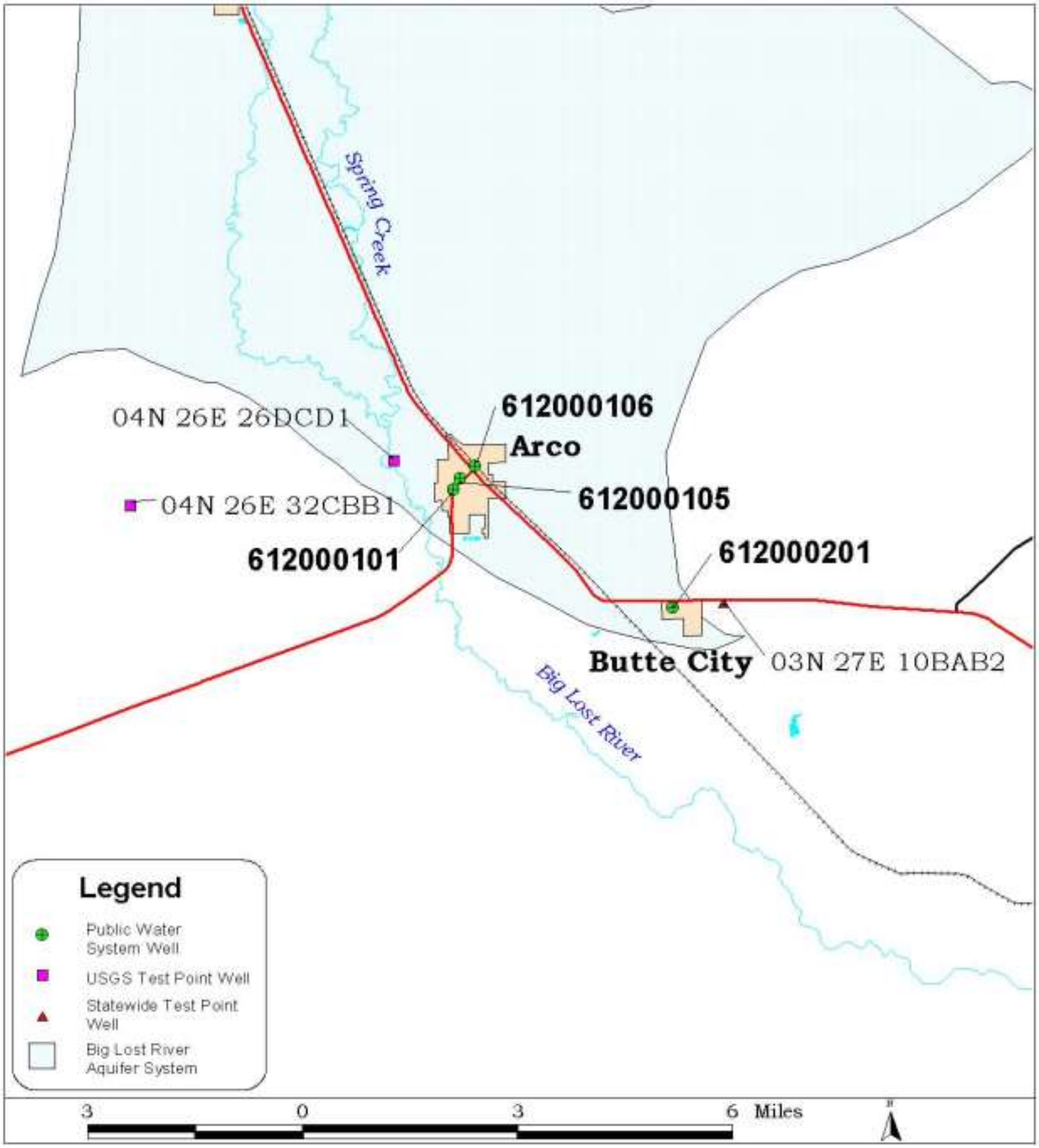


Figure A-4. Arco and Butte PWS Wells.

Attachment B
Hydraulic Property Calculations

PWS #6120022 - Moore Water & Sewer Association Well #1

Given:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

$Q := 445 \cdot gpm$ ...pumping rate $s := 21.83 ft$ ...drawdown $t := 6 \cdot hr$ ...time

$Q_s := \frac{Q}{s}$ $Q_s = 20.38 \frac{gpm}{ft}$ ...specific capacity $r_w := 6 \cdot in$ ...radius

$S := .001$ ...storage (Bassick and Jones, 1992))

$b := 46 \cdot ft$ ...aquifer thickness (125' - 171' bgs)

Calculate transmissivity (T) and hydraulic conductivity (K) using series approximation of Theis (1935) solution (Lohman, 1979, p. 15):

$u(T) := \frac{r_w^2 \cdot S}{4 \cdot T \cdot t}$ $\gamma \equiv 0.5772156649$ $n := 1..50$

$w(u) := -\gamma - \ln(u) - \sum_n \frac{(-1)^n \cdot u^n}{n \cdot n!}$ $W(u) := \begin{cases} w(u) & \text{if } w(u) > 0 \\ 0 & \text{otherwise} \end{cases}$ ...well function

check values of well function against table in Groundwater by Freeze and Cherry, 1979, p. 3

$W(9) = 1.2 \cdot 10^{-5}$ $W(10^{-8}) = 17.84$ $W(10^{-15}) = 33.96$

$T := 10^6 \cdot \frac{gpd}{ft}$ ...initial guess at transmissivity

Given

$T = \frac{Q_s \cdot W(u(T))}{4 \cdot \pi}$ ...Theis (1935) solution written in terms of specific capacity

$Trans := Find(T)$

$Trans = 4 \cdot 10^4 \frac{gpd}{ft}$ ...transmissivity $u(Trans) = 4.93 \cdot 10^{-8}$ ...corresponding u value

$K := \frac{Trans}{b}$ $K = 110.3 \frac{ft}{day}$ $K = 3.9 \cdot 10^{-2} \frac{cm}{sec}$ $K = 825 \frac{gpd}{ft^2}$ ...hydraulic conductivity

PWS #6120022 - Moore Water & Sewer Association Well #2

Given:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

$Q := 450 \cdot gpm$ ...pumping rate $s := 5\ ft$ ...drawdown $t := 3.5\ hr$ ...time

$Q_s := \frac{Q}{s}$ $Q_s = 90 \cdot \frac{gpm}{ft}$ ...specific capacity $r_w := 6 \cdot in$ ...radius

$S := .001$ ...storage (Bassick and Jones, 1992))

$b := 40 \cdot ft$ ...aquifer thickness (100' - 140' bgs)

Calculate transmissivity (T) and hydraulic conductivity (K) using series approximation of Theis (1935) solution (Lohman, 1979, p. 15):

$u(T) := \frac{r_w{}^2 \cdot S}{4 \cdot T \cdot t}$ $\gamma \equiv 0.5772156649$ $n := 1..50$

$w(u) := -\gamma - \ln(u) - \sum_n \frac{(-1)^n \cdot u^n}{n \cdot n!}$ $W(u) := \begin{cases} w(u) & \text{if } w(u) > 0 \\ 0 & \text{otherwise} \end{cases}$ ...well function

check values of well function against table in Groundwater by Freeze and Cherry, 1979, p. 3

$W(9) = 1.2 \cdot 10^{-5}$ $W\left(10^{-8}\right) = 17.84$ $W\left(10^{-15}\right) = 33.96$

$T := 10^6 \cdot \frac{gpd}{ft}$ ...initial guess at transmissivity

Given

$T = \frac{Q_s \cdot W(u(T))}{4 \cdot \pi}$ ...Theis (1935) solution written in terms of specific capacity

$Trans := Find(T)$

$Trans = 2 \cdot 10^5 \cdot \frac{gpd}{ft}$ ...transmissivity $u(Trans) = 1.8 \cdot 10^{-8}$ ...corresponding u value

$K := \frac{Trans}{b}$ $K = 594.7 \cdot \frac{ft}{day}$ $K = 2.1 \cdot 10^{-1} \cdot \frac{cm}{sec}$ $K = 4449 \cdot \frac{gpd}{ft^2}$ ...hydraulic conductivity

PWS #6120001 - Arco City Fill Station Well

Given:

$gpm \equiv \frac{gal}{min}$ $\quad gpd \equiv \frac{gal}{day}$

$Q := 1200\,gpm$ ...pumping rate $\quad s := 26\,ft$ ...drawdown $\quad t := 12\cdot hr$ ...time

$Q_s := \frac{Q}{s}$ $\quad Q_s = 46.15 \frac{gpm}{ft}$ ...specific capacity $\quad r_w := 10\cdot in$ ...radius

$S := .001$ ...storage (Bassick and Jones, 1992))

$b := 16\cdot ft$ ...aquifer thickness (198' - 214' bgs)

Calculate transmissivity (T) and hydraulic conductivity (K) using series approximation of Theis (1935) solution (Lohman, 1979, p. 15):

$u(T) := \frac{r_w^{\,2}\cdot S}{4\cdot T\cdot t}$ $\quad \gamma \equiv 0.5772156649$ $\quad n := 1..50$

$w(u) := -\gamma - \ln(u) - \sum_n \frac{(-1)^n\cdot u^n}{n\cdot n!}$ $\quad W(u) := \begin{cases} w(u) & \text{if } w(u) > 0 \\ 0 & \text{otherwise} \end{cases}$ ...well function

check values of well function against table in Groundwater by Freeze and Cherry, 1979, p. 3

$W(9) = 1.2\cdot 10^{-5}$ $\quad W(10^{-8}) = 17.84$ $\quad W(10^{-15}) = 33.96$

$T := 10^6\cdot \frac{gpd}{ft}$ ...initial guess at transmissivity

Given

$T = \frac{Q_s\cdot W(u(T))}{4\cdot\pi}$ ...Theis (1935) solution written in terms of specific capacity

$Trans := Find(T)$

$Trans = 9\cdot 10^4 \frac{gpd}{ft}$ ...transmissivity $\quad u(Trans) = 2.93\cdot 10^{-8}$ ...corresponding u value

$K := \frac{Trans}{b}$ $\quad K = 741 \frac{ft}{day}$ $\quad K = 2.6\cdot 10^{-1} \frac{cm}{sec}$ $\quad K = 5543 \frac{gpd}{ft^2}$ ...hydraulic conductivity

PWS #6120002 - Butte City PWS Well #1

Given:

$gpm \equiv \frac{gal}{min}$ $gpd \equiv \frac{gal}{day}$

$Q := 125 \cdot gpm$ ...pumping rate $s := 15\,ft$ ...drawdown $t := 3 \cdot hr$ ...time

$Q_s := \frac{Q}{s}$ $Q_s = 8.33 \cdot \frac{gpm}{ft}$ ...specific capacity $r_w := 6 \cdot in$ ...radius

$S := .001$ ...storage (Bassick and Jones, 1992))

$b := 14 \cdot ft$ ...aquifer thickness (461' - 475' bgs)

Calculate transmissivity (T) and hydraulic conductivity (K) using series approximation of Theis (1935) solution (Lohman, 1979, p. 15):

$u(T) := \frac{r_w^{\,2} \cdot S}{4 \cdot T \cdot t}$ $\gamma \equiv 0.5772156649$ $n := 1..50$

$w(u) := -\gamma - \ln(u) - \sum_n \frac{(-1)^n \cdot u^n}{n \cdot n!}$ $W(u) := \begin{vmatrix} w(u) \text{ if } w(u) > 0 \\ 0 \text{ otherwise} \end{vmatrix}$ ...well function

check values of well function against table in Groundwater by Freeze and Cherry, 1979, p. 3

$W(9) = 1.2 \cdot 10^{-5}$ $W\left(10^{-8}\right) = 17.84$ $W\left(10^{-15}\right) = 33.96$

$T := 10^6 \cdot \frac{gpd}{ft}$ ...initial guess at transmissivity

Given

$T = \frac{Q_s \cdot W(u(T))}{4 \cdot \pi}$ ...Theis (1935) solution written in terms of specific capacity

$Trans := Find(T)$

$Trans = 1 \cdot 10^4 \cdot \frac{gpd}{ft}$ ...transmissivity $u(Trans) = 2.69 \cdot 10^{-7}$ ...corresponding u value

$K := \frac{Trans}{b}$ $K = 132.7 \cdot \frac{ft}{day}$ $K = 4.7 \cdot 10^{-2} \cdot \frac{cm}{sec}$ $K = 992 \cdot \frac{gpd}{ft^2}$ ...hydraulic conductivity

Attachment C
Calibration Runs

Big Lost River Valley (Mackay)

Calibration Run 1

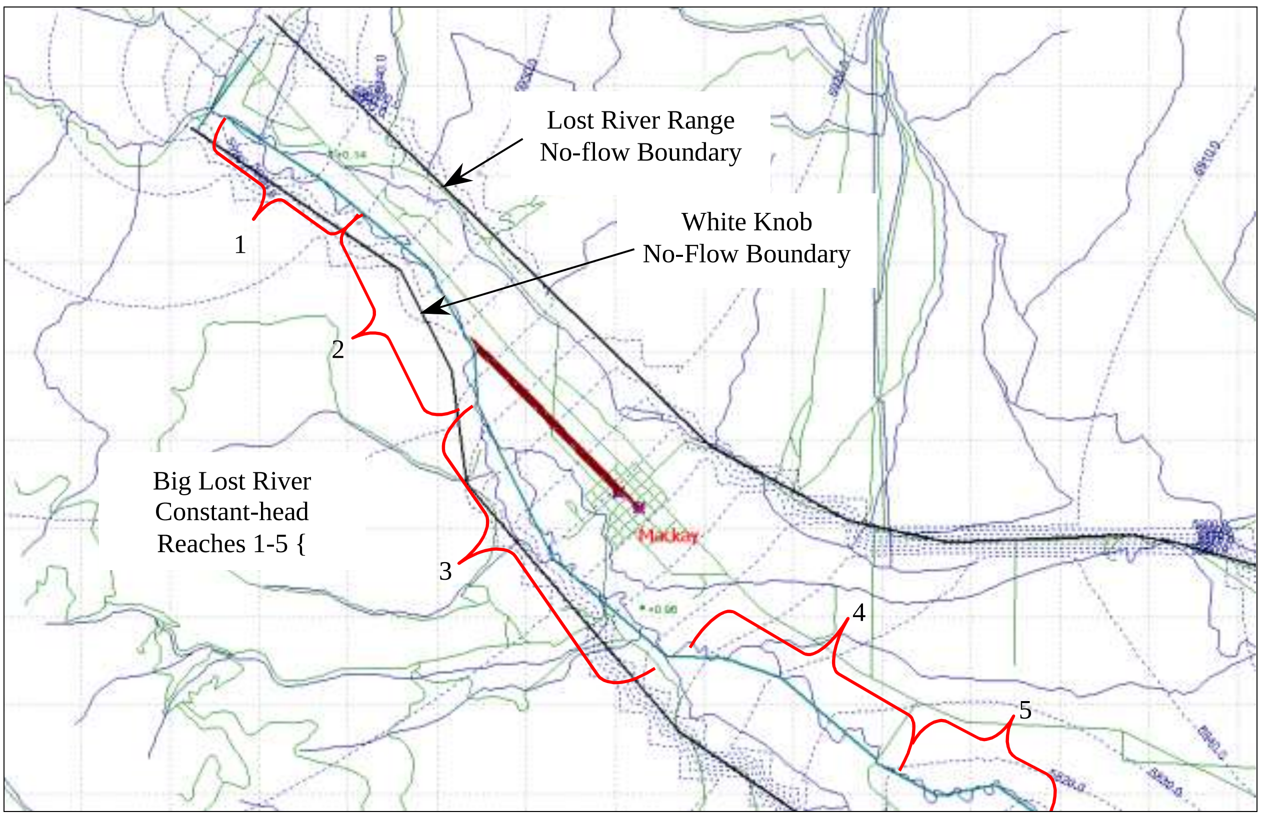
Constant-head Line Sinks (ft msl)

Northern	6000	**Big Lost River 1**	5992 to 5980	**Big Lost River 2**	5980 to 5915
Big Lost River 3	5915 to 5855	**Big Lost River 4**	5855 to 5820	**Big Lost River 5**	5820 to 5780

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge
767	5799	65	0.3	0.00023

Name	Obs Head	Calc Head	Difference (R)	Count Well?	R2
07N 24E 07CCB3	5980.3	5980.44	0.14	Y	0.0196
07N 24E 26CDD1	5866.5	5867.46	0.96	Y	0.9216

Sum of Squares	0.941
Root Mean Squared Error	0.686
Avg. Head Difference	0.550



Good fit at test point well locations. Recharge along the bedrock/valley-fill contact is not represented.

Big Lost River Valley (Mackay)

Calibration Run 3

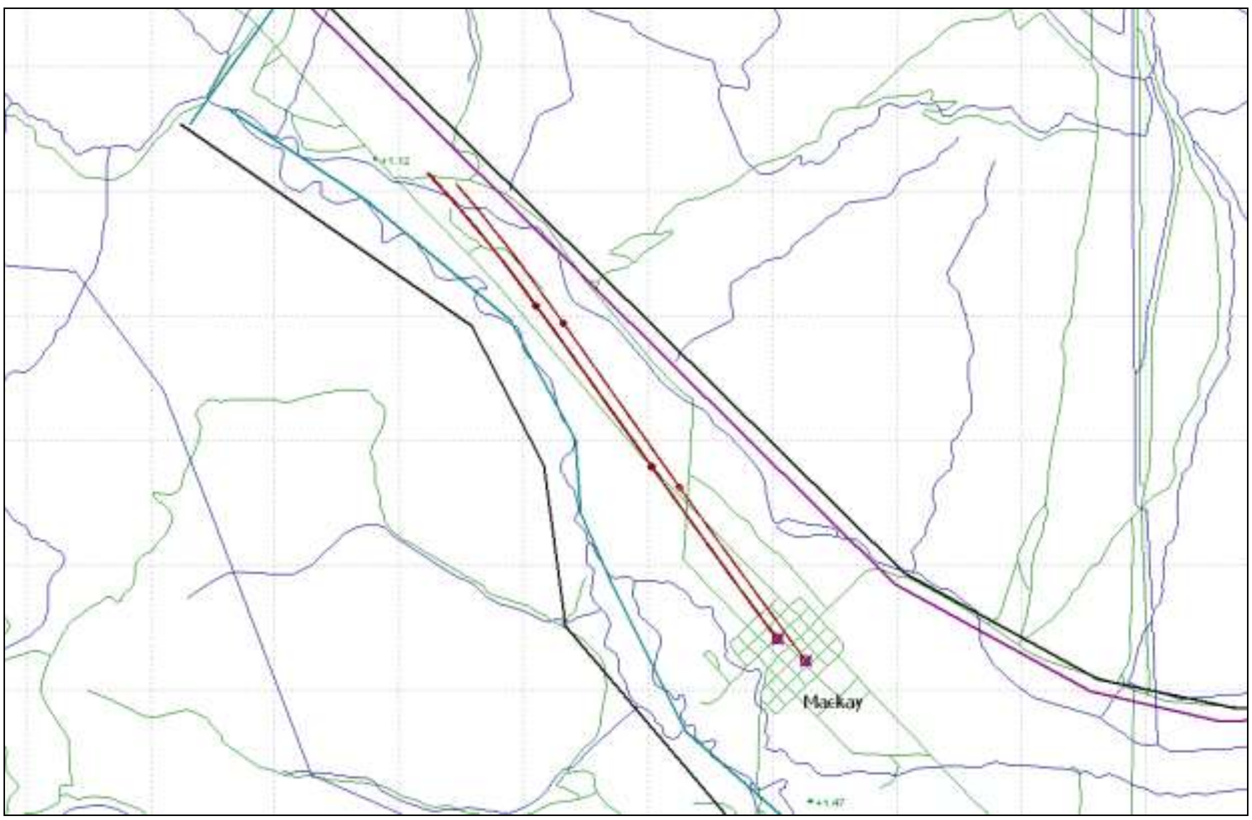
Constant-head Line Sinks (ft msl)

Northern	6000	**Big Lost River 1**	5992 to 5980	**Big Lost River 2**	5980 to 5915
Big Lost River 3	5915 to 5855	**Big Lost River 4**	5855 to 5820	**Big Lost River 5**	5820 to 5780
Lost River Range	-50				

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge
767	5799	65	0.3	0.00023

Name	Obs Head	Calc Head	Difference (R)	Count Well?	R2
07N 24E 07CCB3	5980.3	5981.42	1.12	Y	1.2544
07N 24E 26CDD1	5866.5	5867.97	1.47	Y	2.1609

Sum of Squares	3.415
Root Mean Squared Error	1.307
Avg. Head Difference	1.295



Goodness of fit is not as good as run 1. However, aquifer recharge from the bedrock/valley-fill contact is better represented. Orientation of the particle path has shifted ~9° to the north as a result of the increased recharge. **Base Case.**

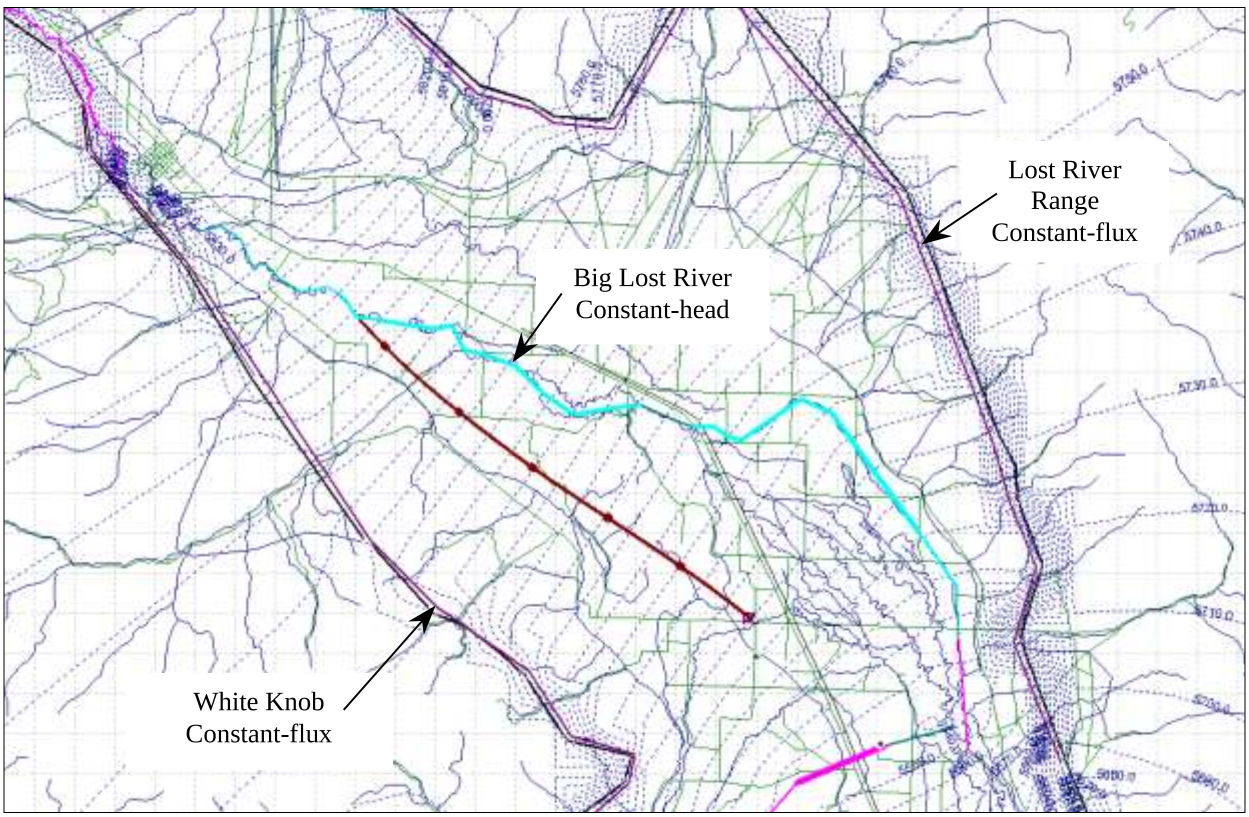
Big Lost River Valley (Antelope Creek)

Calibration Run 1

Constant-head Line Sinks (ft msl)				Flux Line Sinks (ft^2/day)	
Northern	5900	Southern	5533	White Knob	-1
Big Lost River	5952 to 5530			Lost River	-6

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
1419	5484	16	0.3	0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
05N 26E 05DCB1	5539	5537.59	-1.41	Y	1.9881
06N 25E 03AAA1	5689	5688.67	-0.33	Y	0.1089
06N 25E 36DBB1	5588	5589.95	1.95	Y	3.8025

Sum of Squares	5.899
Root Mean Squared Error	1.402
Avg. Head Difference	0.070



Good fit at test point well locations. Very low average head difference.

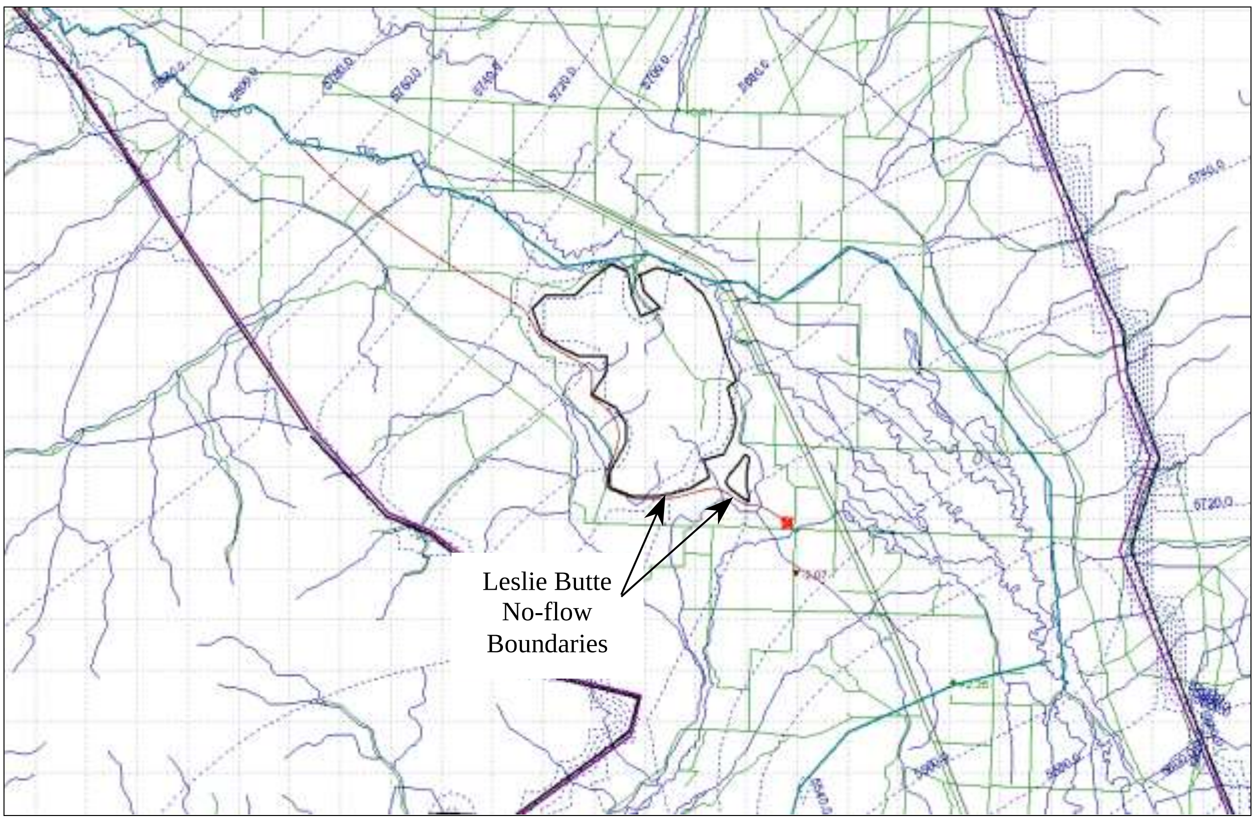
Big Lost River Valley (Antelope Creek)

Calibration Run 2

Constant-head Line Sinks (ft msl)				Flux Line Sinks (ft^2/day)	
Northern	5900	Southern	5533	White Knob	-8
Big Lost River	5952 to 5530			Lost River	-4

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
1419	5484	16	0.3	0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
05N 26E 05DCB1	5539	5541.35	2.35	Y	5.5225
06N 25E 03AAA1	5689	5689.81	0.81	Y	0.6561
06N 25E 36DBB1	5588	5585.93	-2.07	Y	4.2849

Sum of Squares	10.464
Root Mean Squared Error	1.868
Avg. Head Difference	0.363



A no-flow boundary representing Leslie Butte was add to the model. This resulted in a slightly poorer calibration statistics, yet a more realsitic flow path. **Base Case 1.**

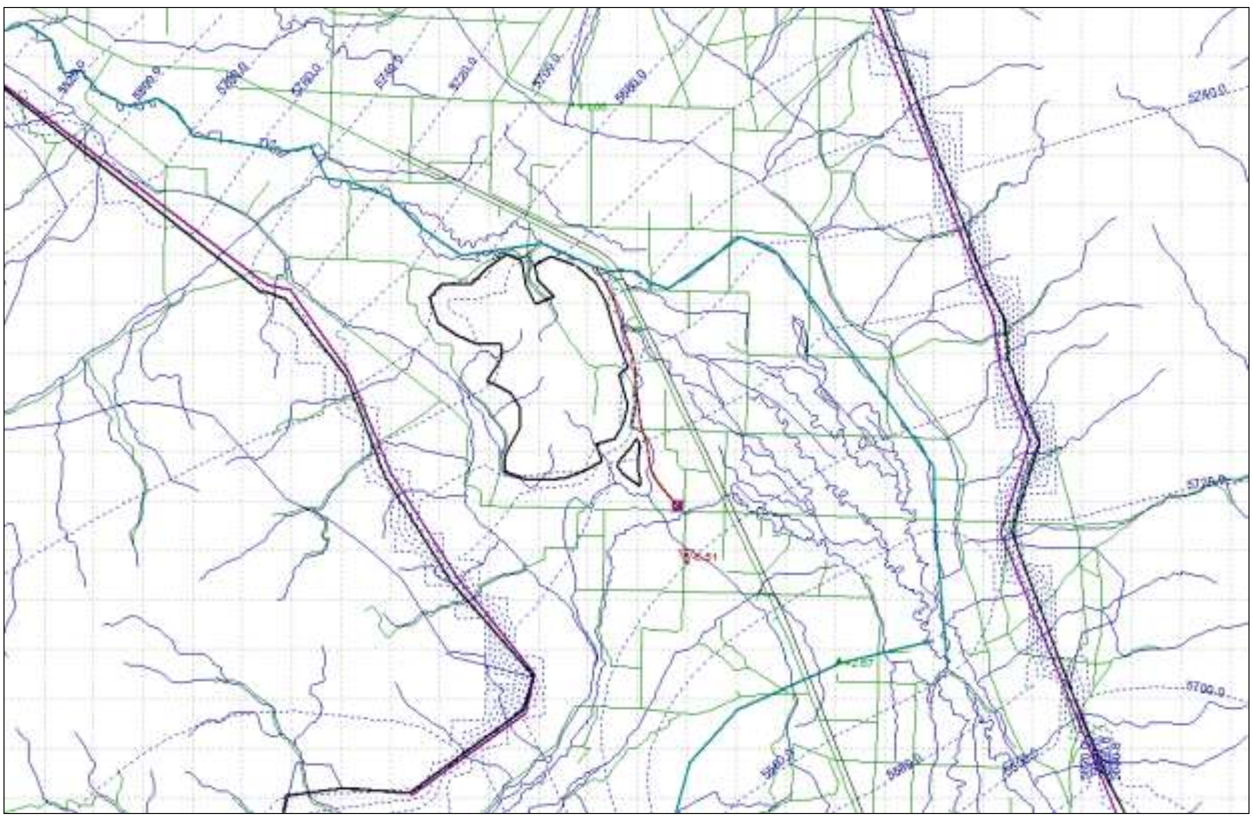
Big Lost River Valley (Antelope Creek)

Calibration Run 3

Constant-head Line Sinks (ft msl)				Flux Line Sinks (ft^2/day)	
Northern	5900	Southern	5533	White Knob	-8
Big Lost River	5952 to 5530			Lost River	-4

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
1419	5484	16	0.3	0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
05N 26E 05DCB1	5539	5541.67	2.67	Y	7.1289
06N 25E 03AAA1	5689	5690.06	1.06	Y	1.1236
06N 25E 36DBB1	5588	5581.49	-6.51	Y	42.3801

Sum of Squares	50.633
Root Mean Squared Error	4.108
Avg. Head Difference	-0.927



The White Knob constant-flux and no-flow boundaries were moved east to better represent the bedrock/valley-fill contact. Particle paths shifted to the east side of Leslie Butte. **Base Case 2**.

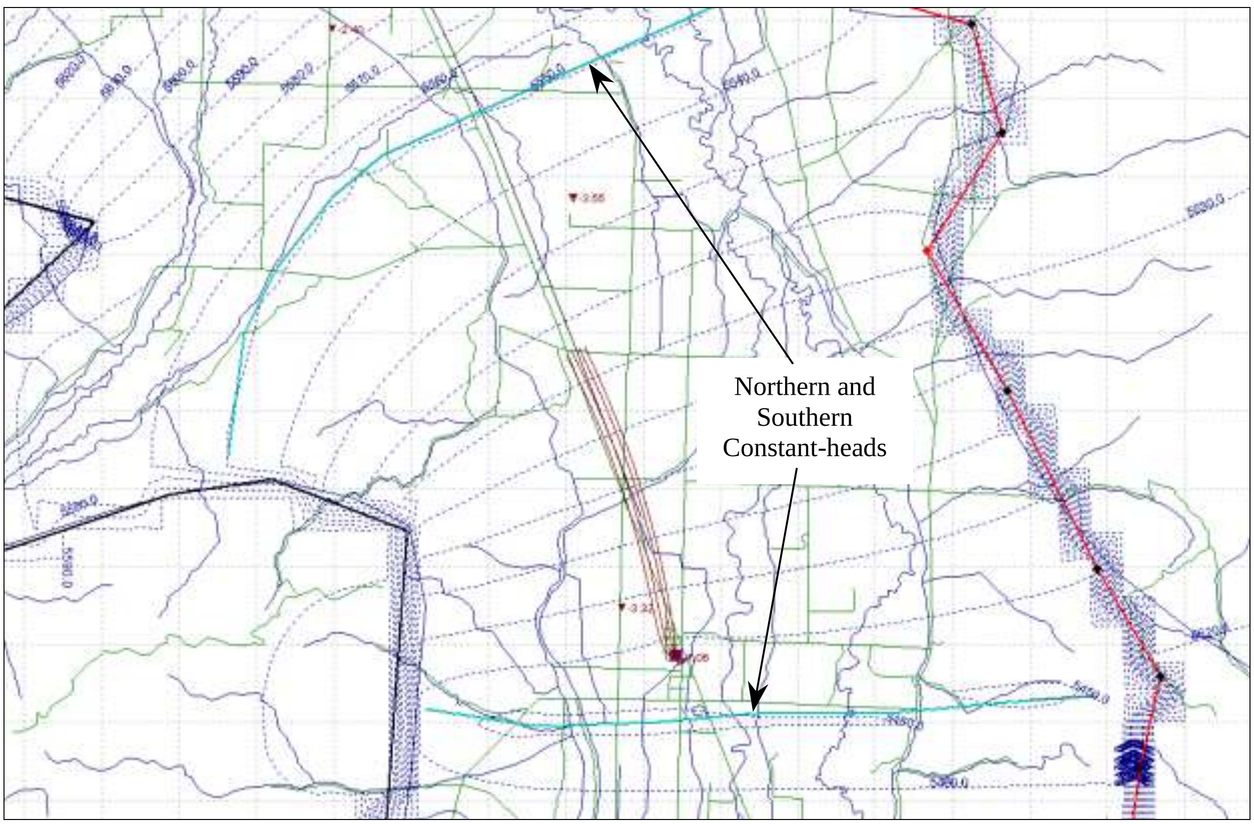
Big Lost River Valley (Moore)

Calibration Run 1

Constant-head (ft msl)		Constant-flux (ft^2/day)
Northern	5550	None
Southern	5448	

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
256	5299	46	0.3	0.00018	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
06N 25E 36DBB1	5588	5585.6	-2.4	Y	5.76
05N 26E 05DCB1	5539	5535.45	-3.55	Y	12.6025
05N 26E 28BBB1	5472	5468.68	-3.32	Y	11.0224
Moore Well #1	5452	5450.94	-1.06	Y	1.1236

Sum of Squares	30.508
Root Mean Squared Error	2.762
Avg. Head Difference	-3.090



Good fit at test point well locations.

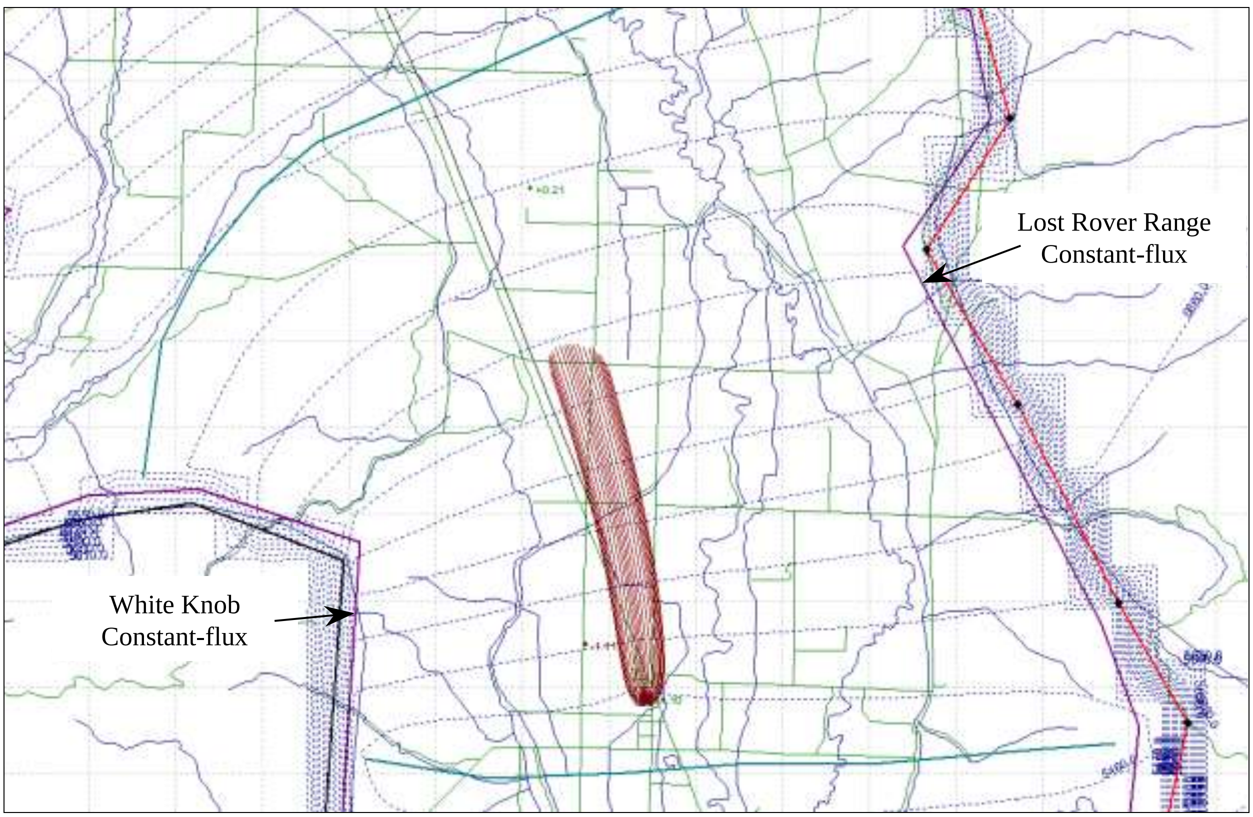
Big Lost River Valley (Moore)

Calibration Run 2

Constant-head (ft msl)		Constant-flux (ft^2/day)	
Northern	5550	Lost River Mt	-10
Southern	5448	White Knob	-2

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
256	5299	46	0.3	0.00018	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
06N 25E 36DBB1	5588	5585.43	-2.57	Y	6.6049
05N 26E 05DCB1	5539	5539.21	0.21	Y	0.0441
05N 26E 28BBB1	5472	5470.89	-1.11	Y	1.2321
Moore Well #1	5452	5453.1	1.1	Y	1.21

Sum of Squares	9.091
Root Mean Squared Error	1.508
Avg. Head Difference	-1.157



Good fit at test point well locations and a 5° shift to the east in the particle path orientation. **Base Case**.

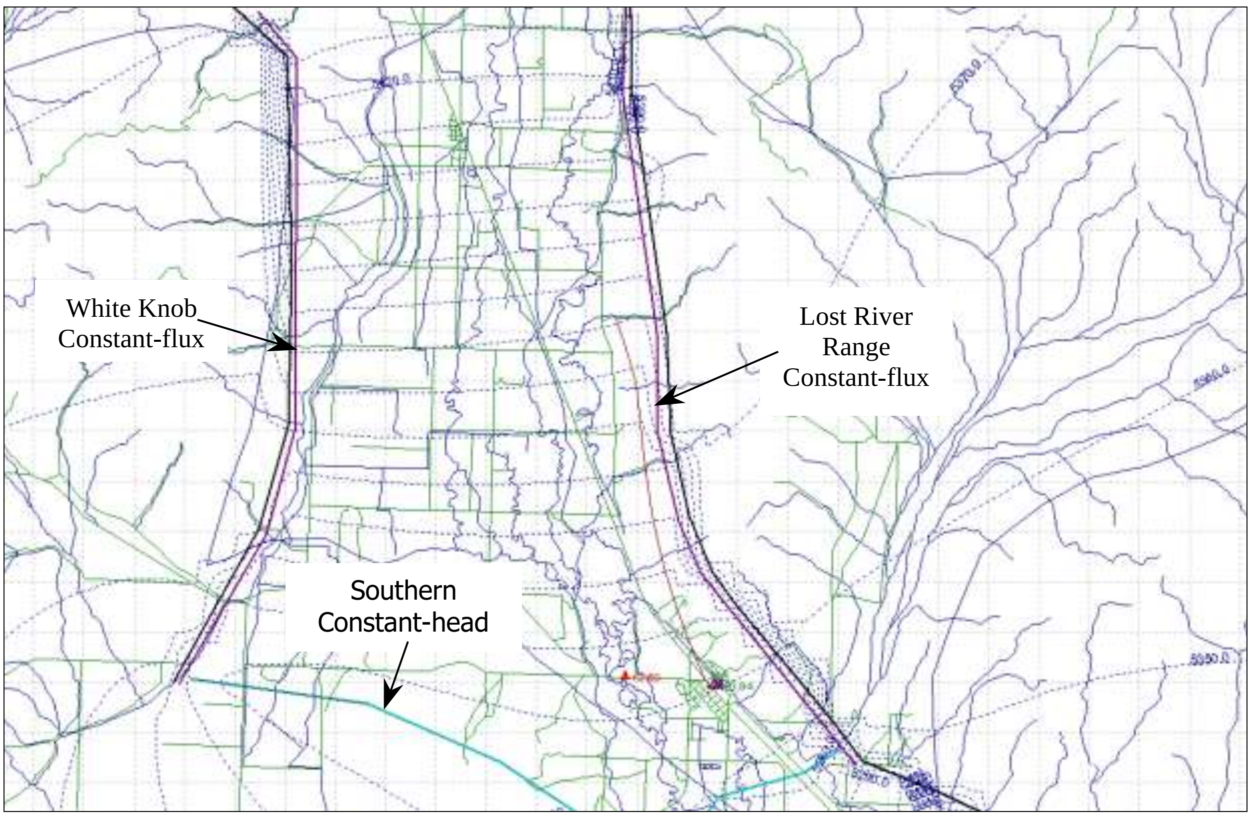
Big Lost River Valley (Arco Fill Station)

Calibration Run 1

Constant-head (ft msl)		Constant-flux (ft²/day)	
Northern	5440	Lost River Mt	-5
Southern	5280	White Knob	-2

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
741	5111	16	0.3	0.0009	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
Fill Station Well	5288	5288.84	0.84	Y	0.7056
04N 26E 26DCD1	5292	5295.5	3.5	Y	12.25

Sum of Squares	12.956
Root Mean Squared Error	2.545
Avg. Head Difference	2.170



Good fit at test point well.

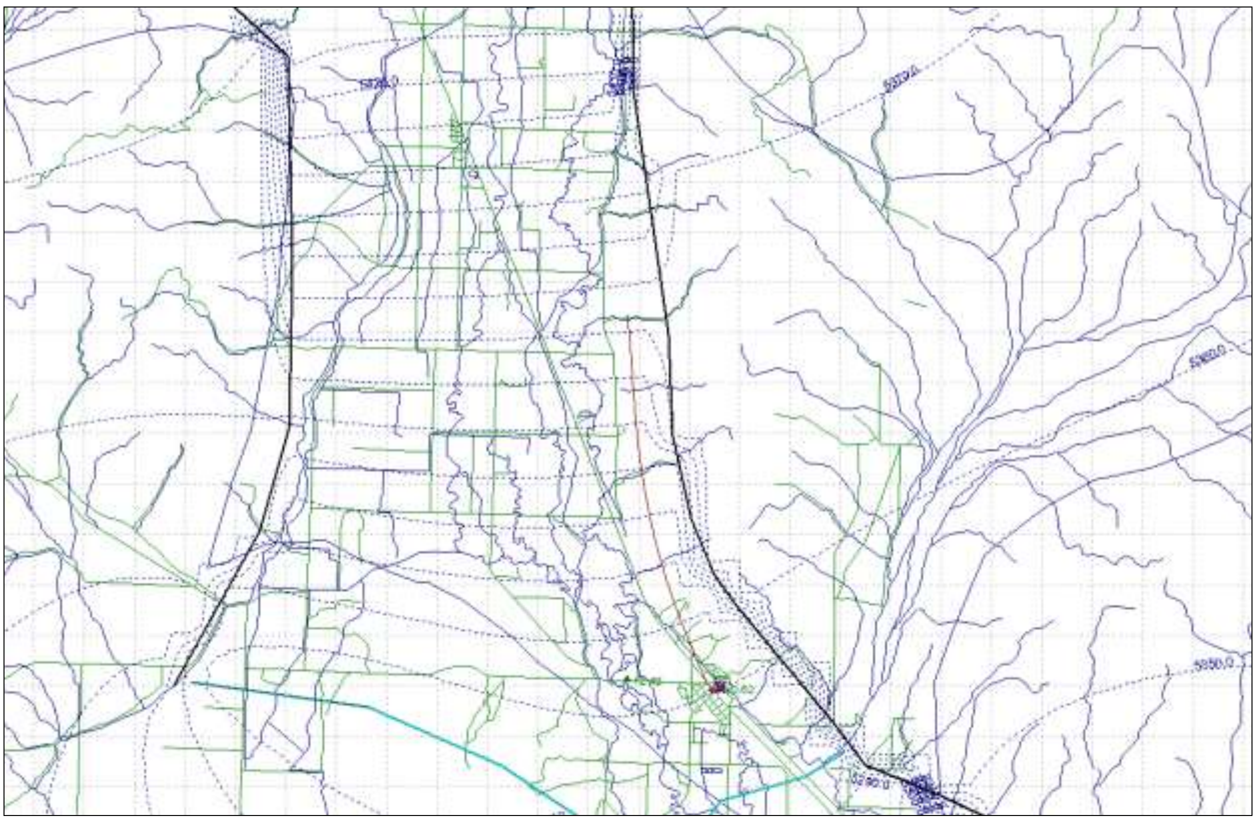
Big Lost River Valley (Arco Fill Station)

Calibration Run 2

Constant-head (ft msl)	
Northern	5440
Southern	5280

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
741	5111	16	0.3	0.0009	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
Fill Station Well	5288	5288.62	0.62	Y	0.3844
04N 26E 26DCD1	5292	5294.42	2.42	Y	5.8564

Sum of Squares	6.241
Root Mean Squared Error	1.766
Avg. Head Difference	1.520



Improved goodness of fit by removing constant-flux line sinks on the basin boundaries. There is little change to particle path orientation. **Base Case.**

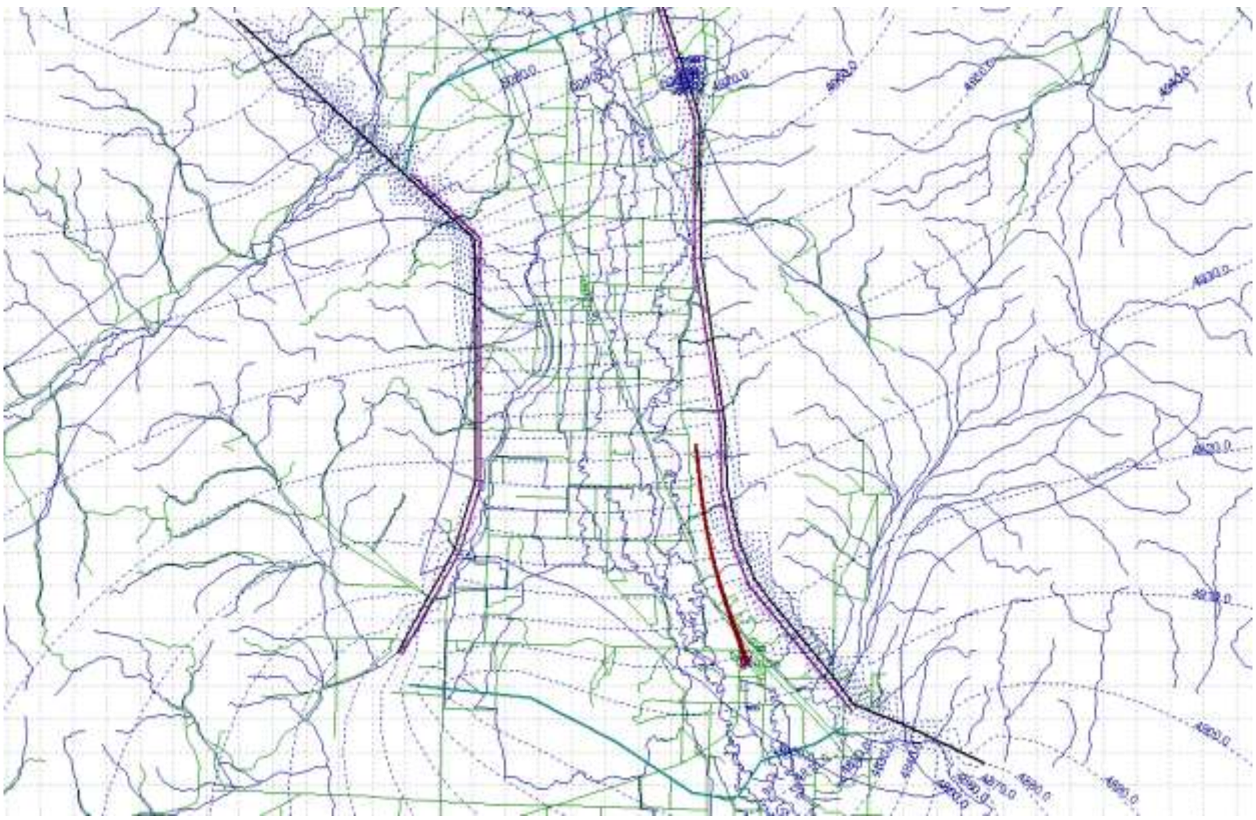
Big Lost River Valley (Arco Water Street Well)

Calibration Run 1

Constant-head (ft msl)		Constant-flux (ft^2/day)	
Northern	5060	**Lost River Mt**	-10
Southern	4800	**White Knob**	-2

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
685	4662	120	0.15	0.0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
Water St. Well	4817	4817.38	0.38	Y	0.1444

Sum of Squares	0.144
Root Mean Squared Error	0.380
Avg. Head Difference	0.380



Good fit at test point well location and to land surface gradients.

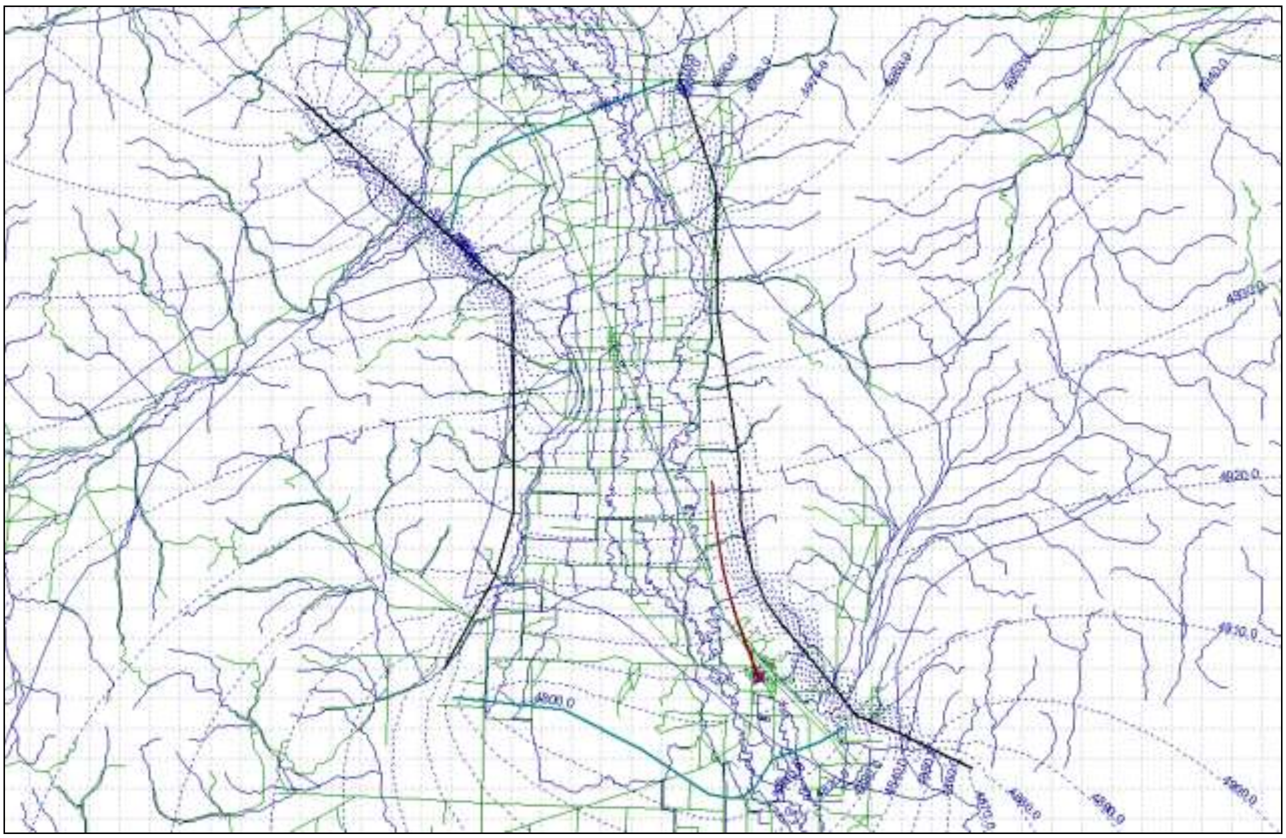
Big Lost River Valley (Arco Water Street Well)

Calibration Run 2

Constant-head (ft msl)	
Northern	5060
Southern	4800

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
685	4662	120	0.15	0.0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
Water St. Well	4817	4817.39	0.39	Y	0.1521

Sum of Squares	0.152
Root Mean Squared Error	0.390
Avg. Head Difference	0.390



Removal of constant-flux line sinks decreased the goodness of fit. There is no notable change in particle path length or orientation. Chosen **Base Case.**

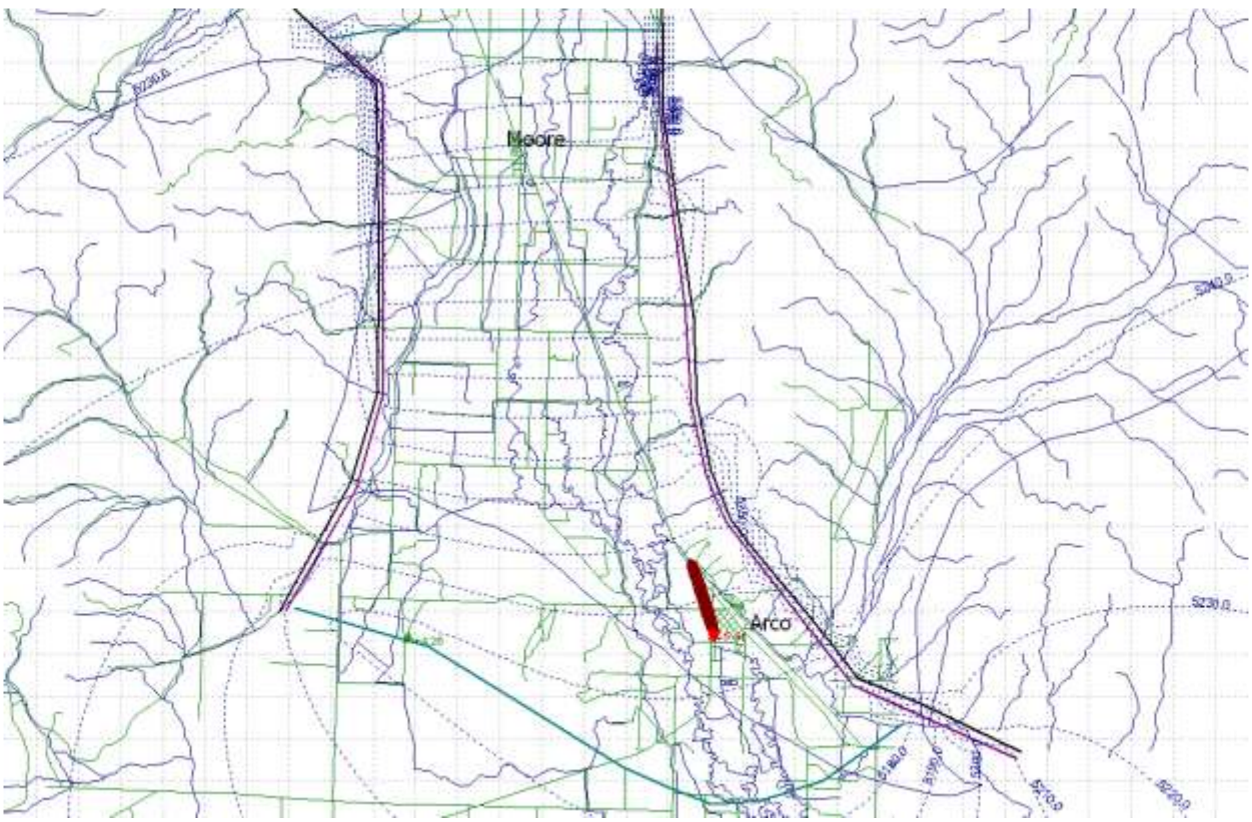
Big Lost River Valley (Arco Park Well)

Calibration Run 1

Constant-head (ft msl)		Constant-flux (ft^2/day)	
Northern	5330	Lost River Mt	-10
Southern	5280	White Knob	-2

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
920	5072	25	0.3	0.0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
Park Well	5189	5183.59	-5.41	Y	29.2681
04N 26E 32CBB1	5170.89	5175.15	4.26	Y	18.1476

Sum of Squares	47.416
Root Mean Squared Error	4.869
Avg. Head Difference	-0.575



Good fit at test point well locations. **Base Case.**

Big Lost River Valley (Arco Park Well)

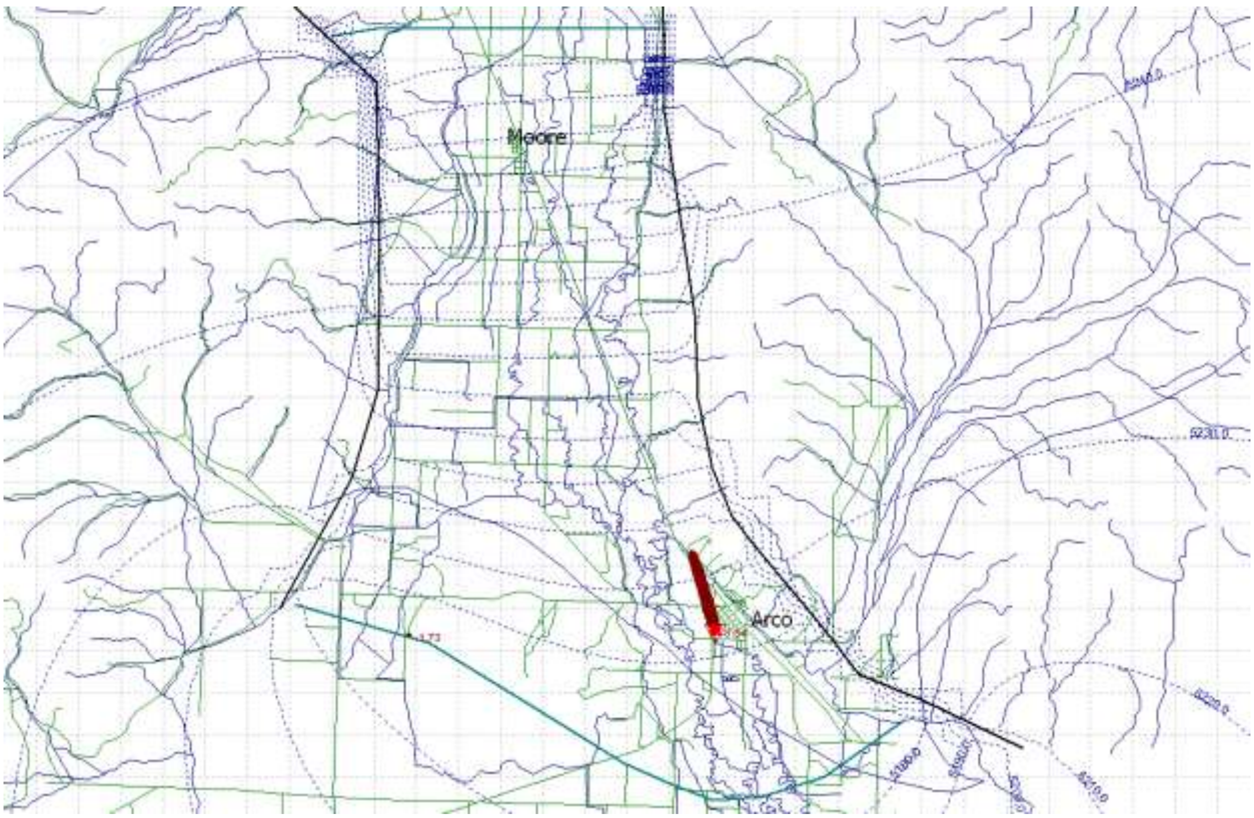
Calibration Run 2

Constant-head (ft msl)

Northern	5330
Southern	5280

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
920	5072	25	0.3	0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
Park Well	5189	5177.04	-11.96	Y	143.0416
04N 26E 32CBB1	5170.89	5169.15	-1.74	Y	3.0276

Sum of Squares	146.069
Root Mean Squared Error	8.546
Avg. Head Difference	-6.850



Poor fit at test point well locations.

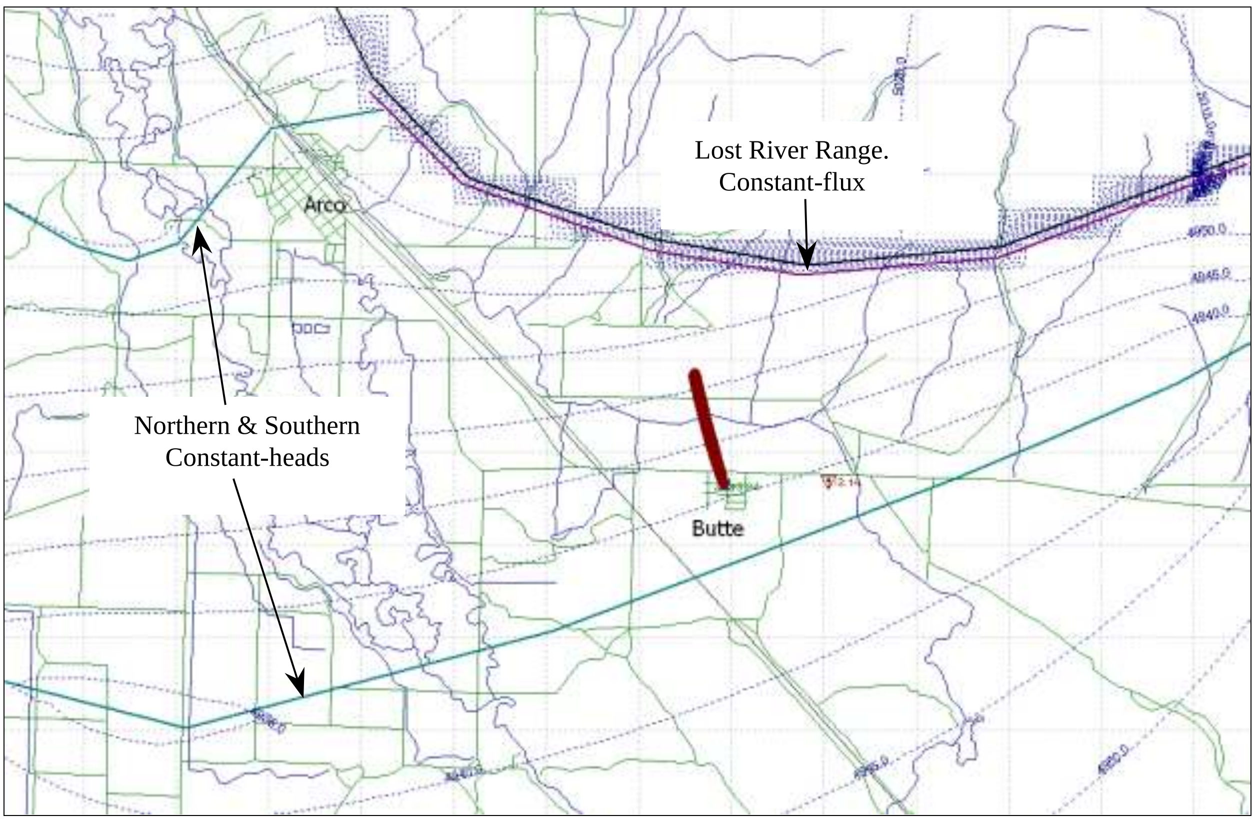
Big Lost River Valley (Butte Well)

Calibration Run 1

Constant-head (ft msl)		Constant-flux (ft^2/day)	
Northern	4965	**Lost River Range**	-5
Southern	4935		

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
133	4841	14	0.3	0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
03N 27E 10BAB2	4942	4938.86	-3.14	Y	9.8596
Butte City Well	4936	4939.84	3.84	Y	14.7456

Sum of Squares	24.605
Root Mean Squared Error	3.508
Avg. Head Difference	0.350



The Butte City well water level was estimated from a surface water elevation obtained from a 1:24,000 topographic map and depth to static water measured shortly after the well completion in the summer of 1960. Good average head difference and sum of squares at test point well locations.

Big Lost River Valley (Butte Well)

Calibration Run 2

Constant-head (ft msl)	
Northern	4965
Southern	4940

K (ft/day)	Base (msl)	Thickness (ft)	Porosity	Recharge	
133	4841	14	0.3	0	
Name	**Obs Head**	**Calc Head**	**Difference (R)**	**Count Well?**	**R2**
03N 27E 10BAB2	4942	4940.59	-1.41	Y	1.9881
Butte City Well	4936	4939.92	3.92	Y	15.3664

Sum of Squares	17.355
Root Mean Squared Error	2.946
Avg. Head Difference	1.255

Good fit to test point wells. Contours are a better fit to Bassick and Jones (1992). **Base Case.**